



Nanotechnology

Overview and Relevance to Occupational Health

Andrew D. Maynard
Chief Science Advisor



Woodrow Wilson
International
Center
for Scholars

THE PEW CHARITABLE TRUSTS

Project on
Emerging Nanotechnologies
at the Woodrow Wilson International Center for Scholars



Nanotechnology and Potential Health Impact



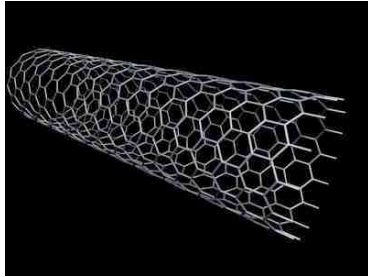
ETC Group Occasional paper Series. Volume 7 No. 1. April 2003

Nanotechnology

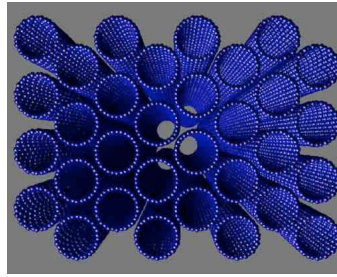
Science Fiction or Science Fact?



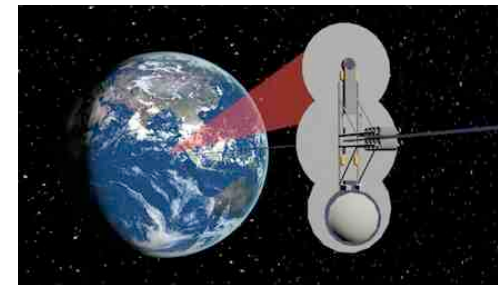
Imagine...



A material where strength is governed by atomic bonds...



... that can be woven into super-strong strands and ropes...



... and used to build an elevator to space!

Nanotechnology is turning fiction to reality...

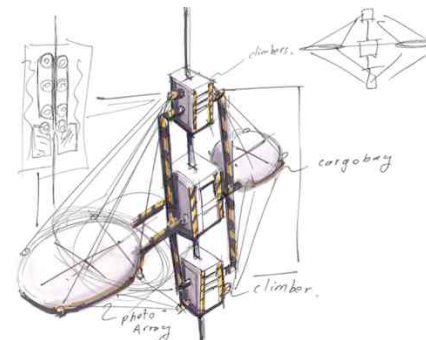
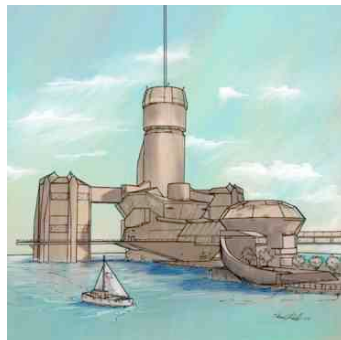


www.liftport.com

LIFTPORT GROUP
THE SPACE ELEVATOR COMPANIES™

Countdown to Lift: April 12, 2018

4891 days, 10 hours, 33 minutes, 42 seconds



Single Walled Carbon nanotubes



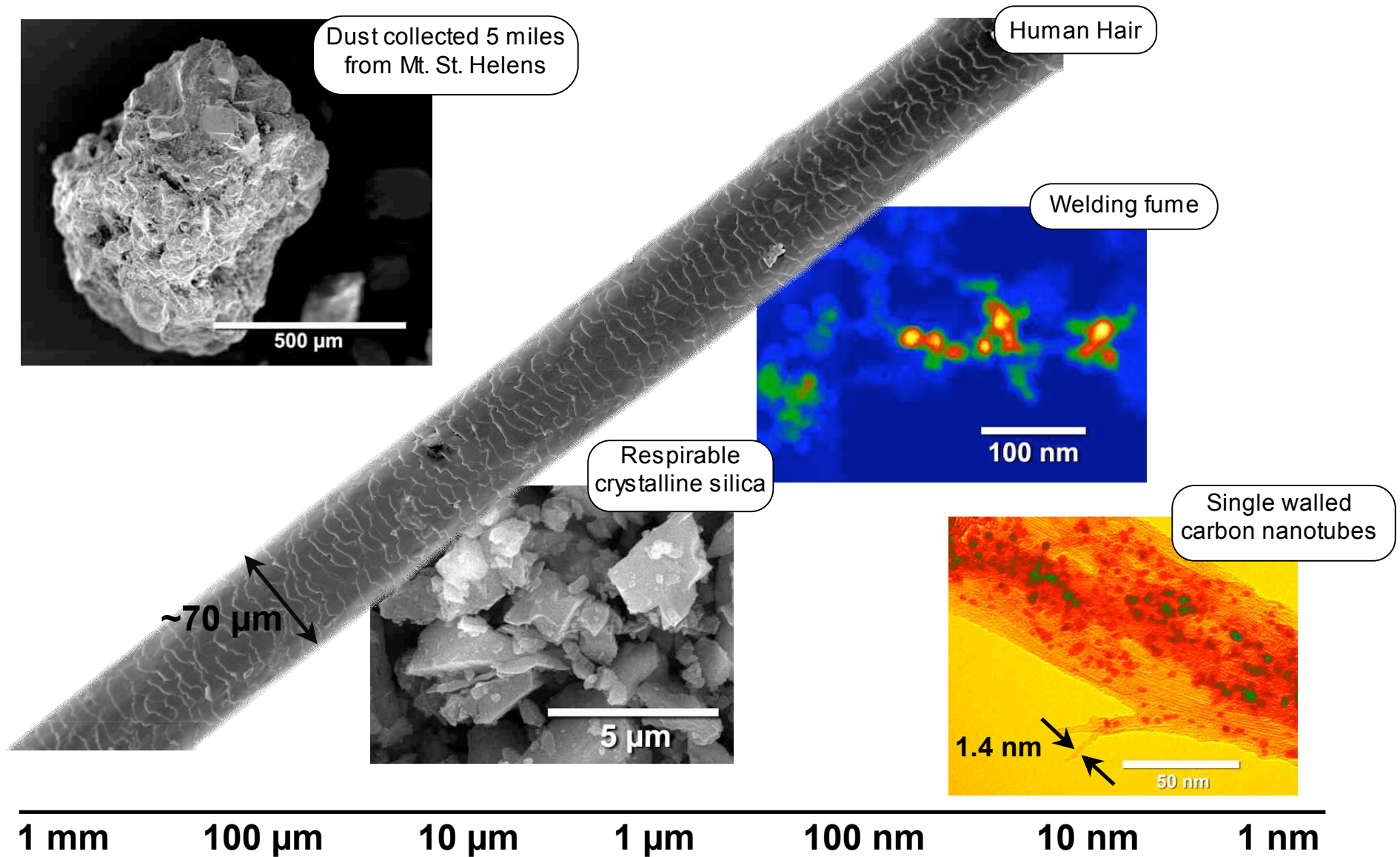
Nanotechnology

- Definition
 - Development/engineering of new devices and materials which demonstrate unique properties associated with structures on a nanometer length-scale
 - Nanometer scale: less than ~ 100 nm
 -
- Includes:
 - Engineered nano-scale surface layers
 - Engineered nano-scale structures (discrete or heterogeneous)
 - Engineered nano-scale devices



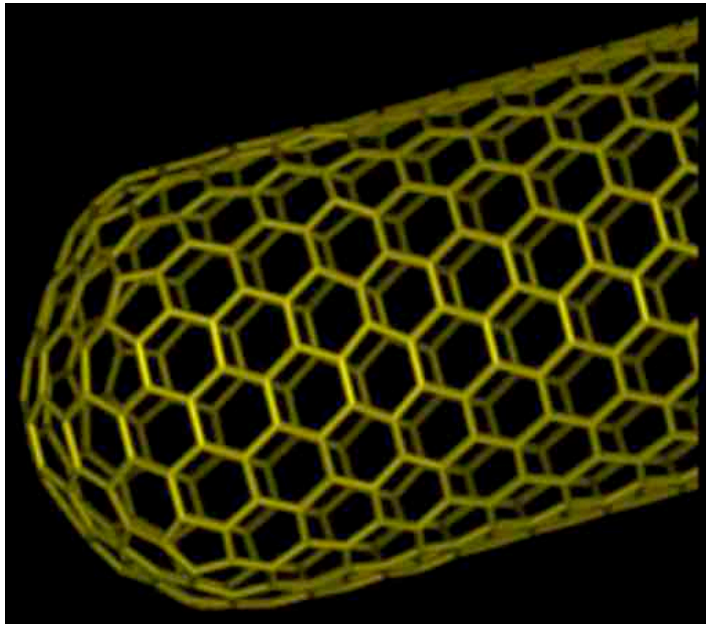
From Micro to Nano..

“Nano” is less than 100 nm

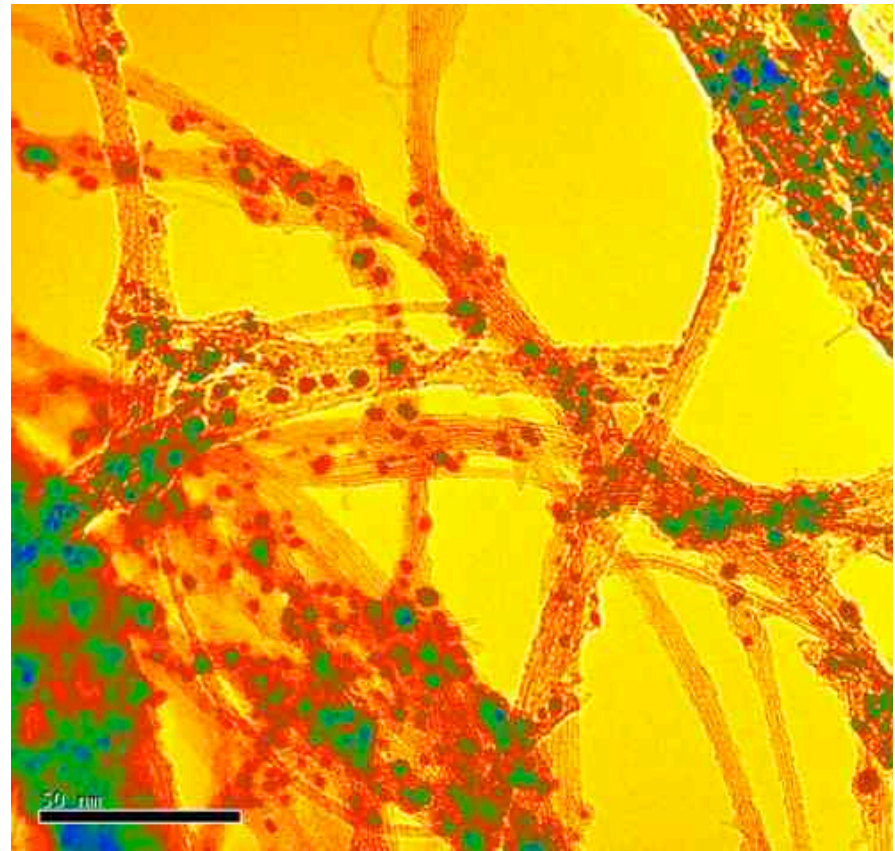


Unique Structures and Morphologies

Single Walled Carbon Nanotubes



- 1.4 nm in diameter
- Micrometers in length
- Unique physical, chemical and electronic properties



Transmission Electron Microscopy

Unique Quantum Properties

Quantum Dots - particle size determines fluorescence



©Felice Frankel. web.mit.edu/felicef. This image is part of the larger “Envisioning Science Project” at MIT

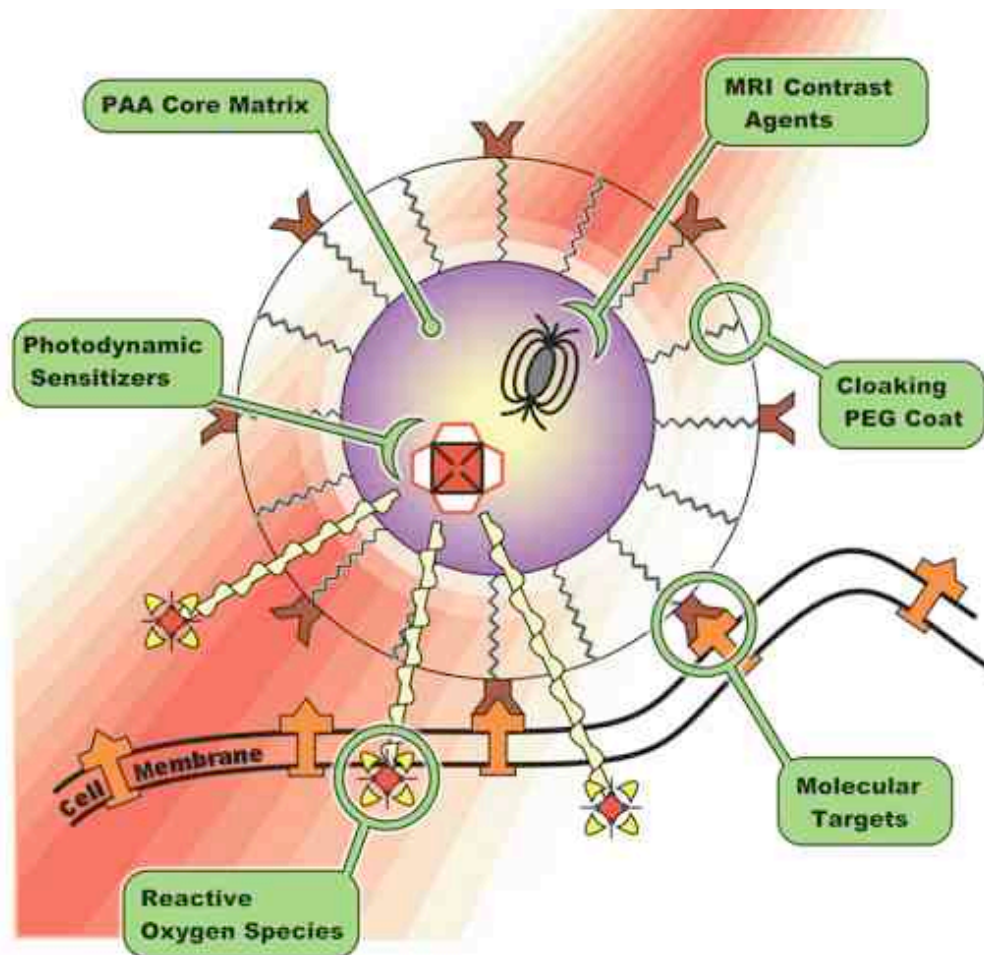
Smaller
particles



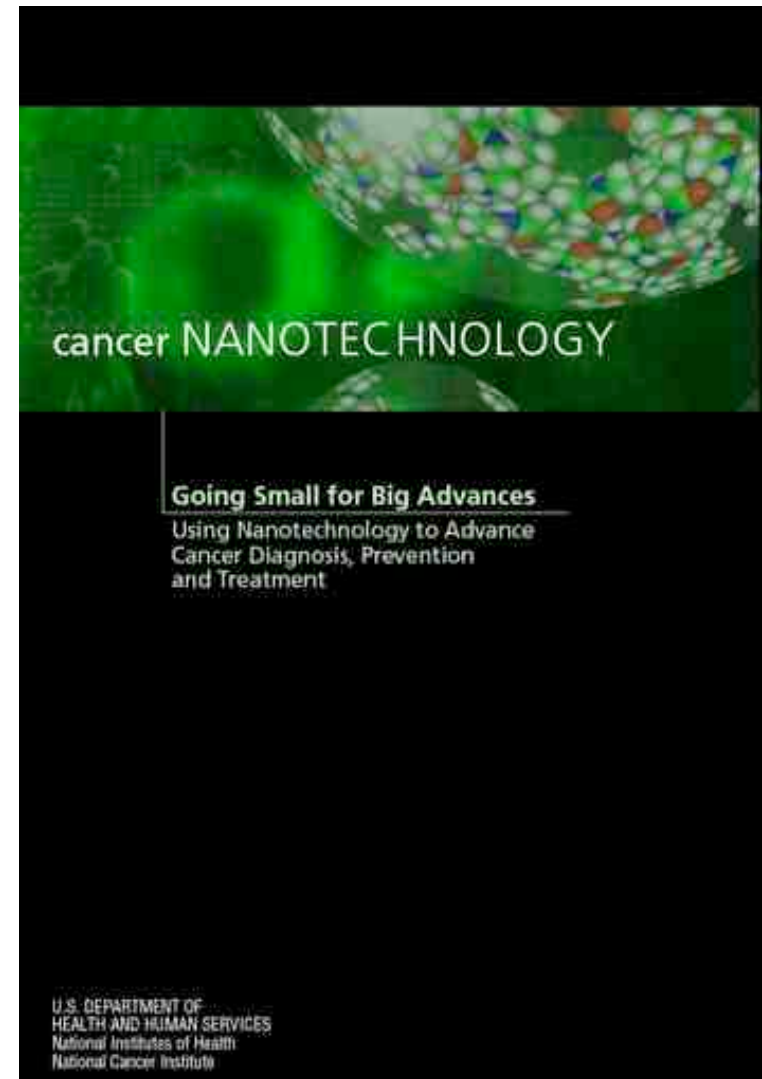
Larger
particles

Unique Devices

'Smart' multifunctional nanoparticles



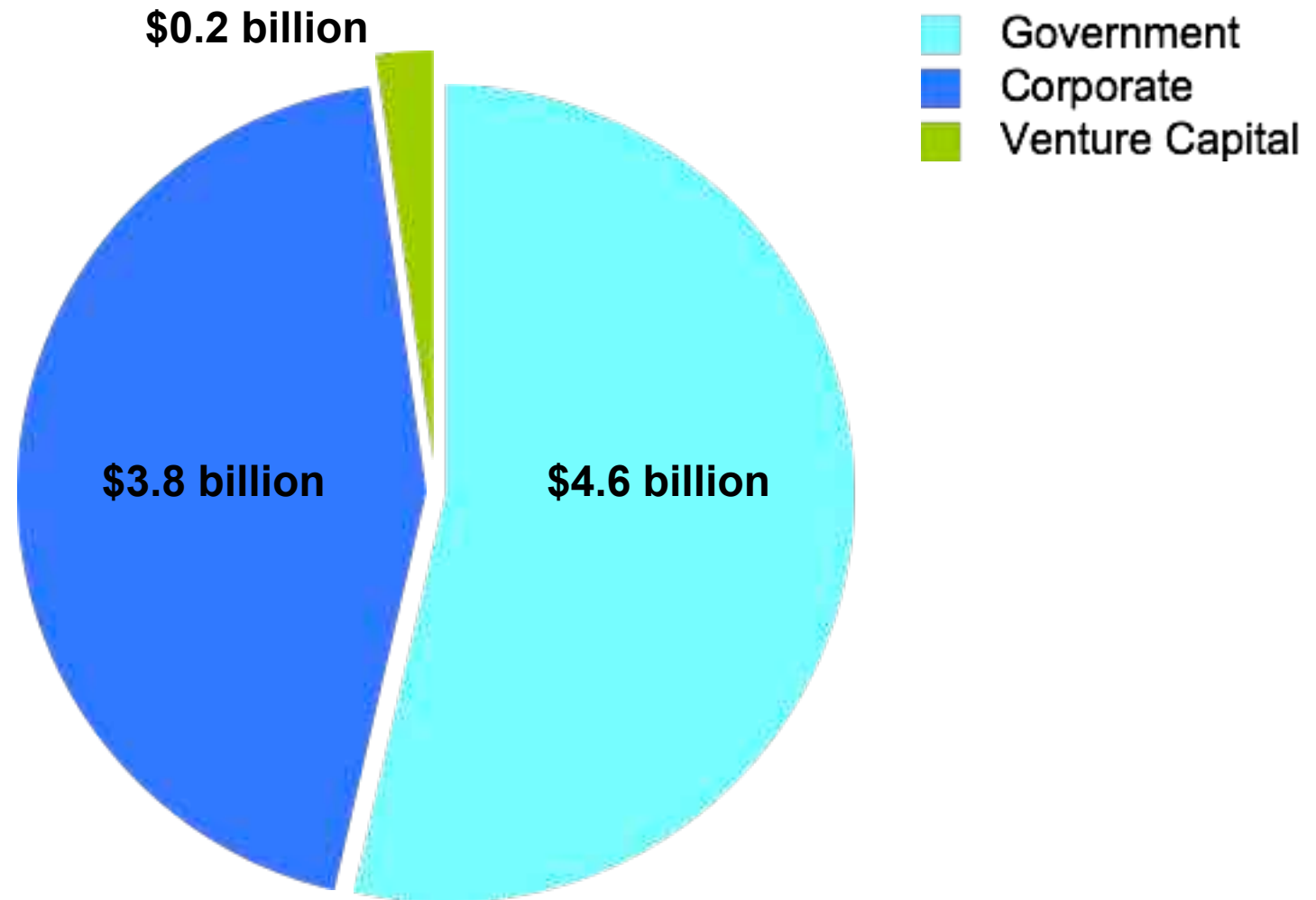
Raoul Kopelman and Martin Philbert, University of Michigan



nano.cancer.gov

Nanotechnology Investment and Impact

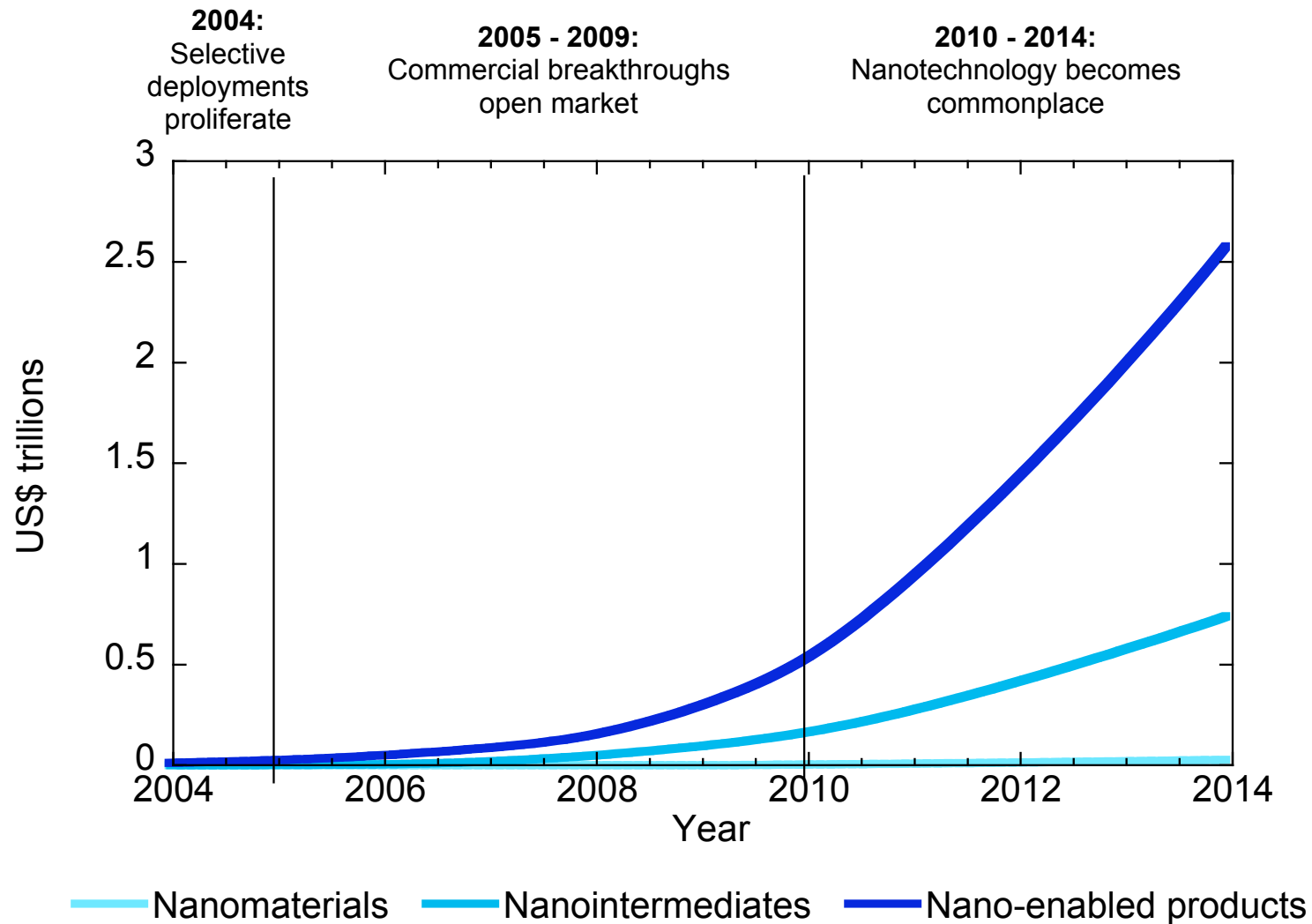
Global R&D Investment in 2004



Source: 2004 Lux Research Reference Study: "The Nanotechnology Report 2004"

Nanotechnology Investment and Impact

Global forecast of products sold incorporating nanotechnology



Source: 2004 Lux Research Report: "Sizing nanotechnology's value chain"

Nanotechnology is 'Now'

Selected consumer products



Nanoclay Composite



www.eastonbike.com

Easton CNT is Real Nanotechnology

The Buckey Ball
Discovered in the 1980s, the Buckey Ball is a spherical molecule of carbon atoms. Each atom is bonded to three other carbon atoms, forming a structure of six carbon hexagons.

The Carbon Nanotube (CNT)
A carbon nanotube is a tube of carbon atoms, each atom bonded to three other carbon atoms, forming a structure of six carbon hexagons.

Easton's Tiny Innovation is Huge
Easton has an eighty-three year history of leading the market by developing new materials and innovative products. Easton has been manufacturing sporting goods using carbon-fiber composites since 1969 and has been the leading brand of composite bicycle handlebars since their introduction in 1989.

Now Easton's research and development team is proud to announce a breakthrough in composite materials and manufacturing.

The Next Frontier
Nanotechnology is the next frontier in scientific research and manufacturing. Nanotechnology deals with the manipulation of matter on an atomic or molecular scale measured in billions of a meter. Many scientists worldwide are spending countless man-hours and billions of dollars on research and development in the areas of electronics, medicine, and structural reinforcement.

Carbon Nanotube Composite

NANOTEX Fabric

resists SPILLS

...ed an iced latte in your lap, but you don't mind, as made with NANO-TEX™ spill-resistant fabric, lifts up and rolls right off.

...e conventional fabric has never been seen before. NANO-TEX builds on the very fibers of fabric to keep the fabric soft, and they should be.

...abric, you're looking good. Spill-proof fabrications roll away like water. Experience the breakthrough and see it's next.

Nano fibers

Filtek™ Supreme Universal Restorative

Say goodbye to microfills and hybrids with our revolutionary new nanocomposite based restorative.

It's good to be King!

3M ESPE

Nanosilica Composite

Defining the Issue

Nanotechnology and Occupational Health



- **Nanotechnology - The Motivation**
- Purposely engineered nanostructured materials and devices demonstrate new, unique and non-scalable properties and behavior
- **Sustainable Nanotechnology - The Challenge**
- Does the nature of engineered nanostructured materials and devices present new safety and health risks?
- How can the benefits of nanotechnology be realized while proactively minimizing the potential risk?

Concern Over the Potential Impact of Nanotechnology

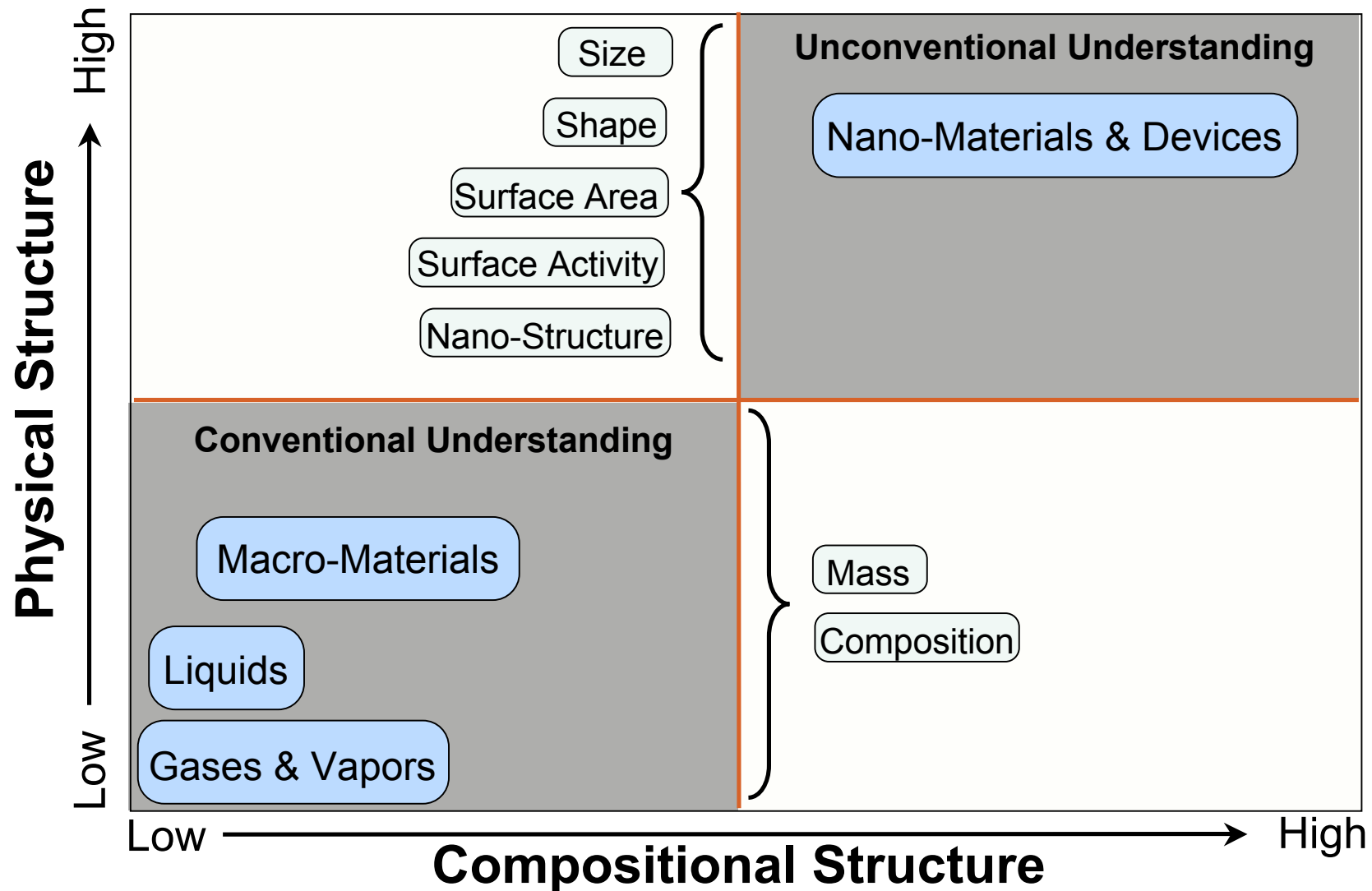


Potential Health Impact

What makes 'nano' different?

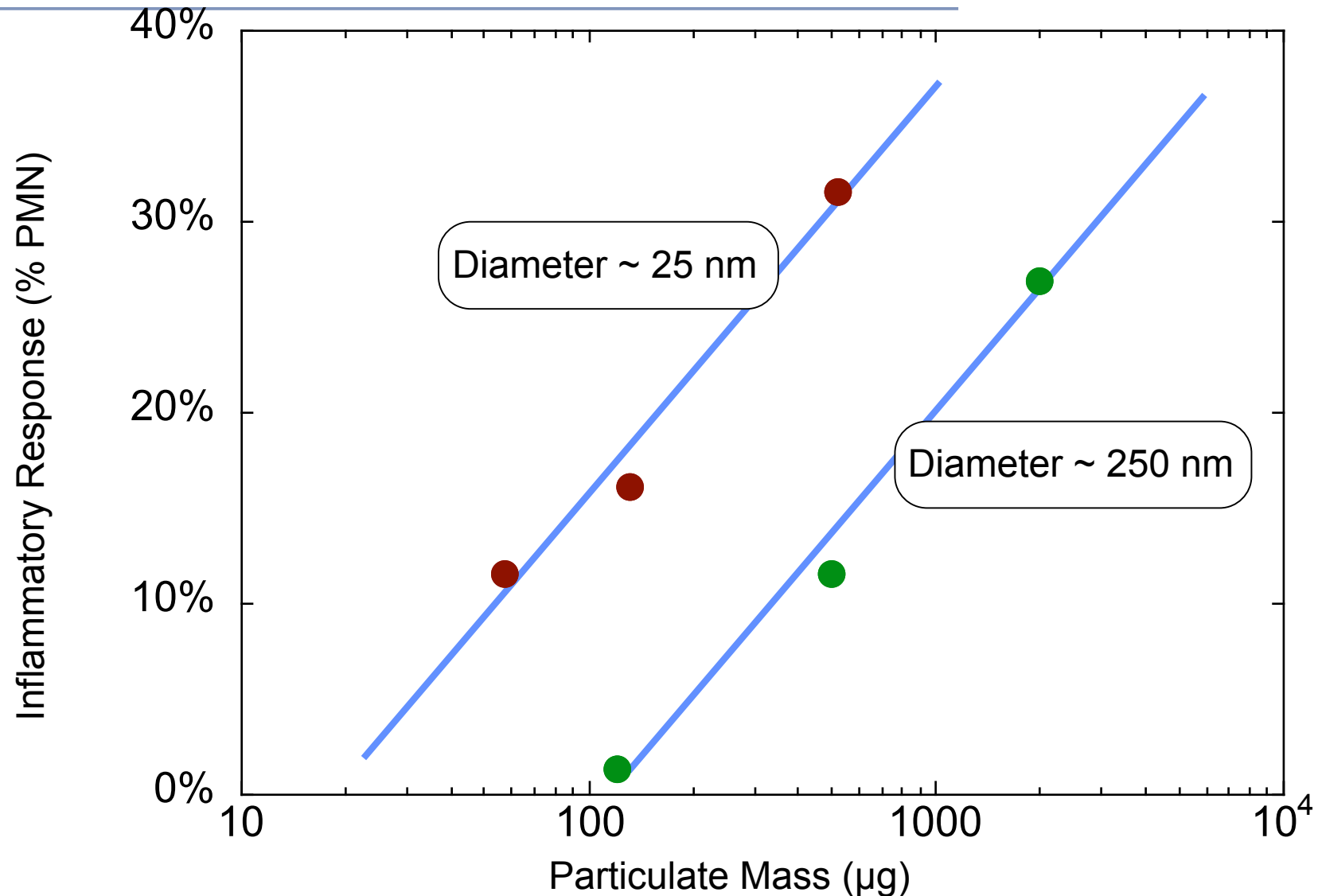


Influence of structure on potential health impact



TiO₂ Instillation in Rats

Oberdörster et al. (2000)

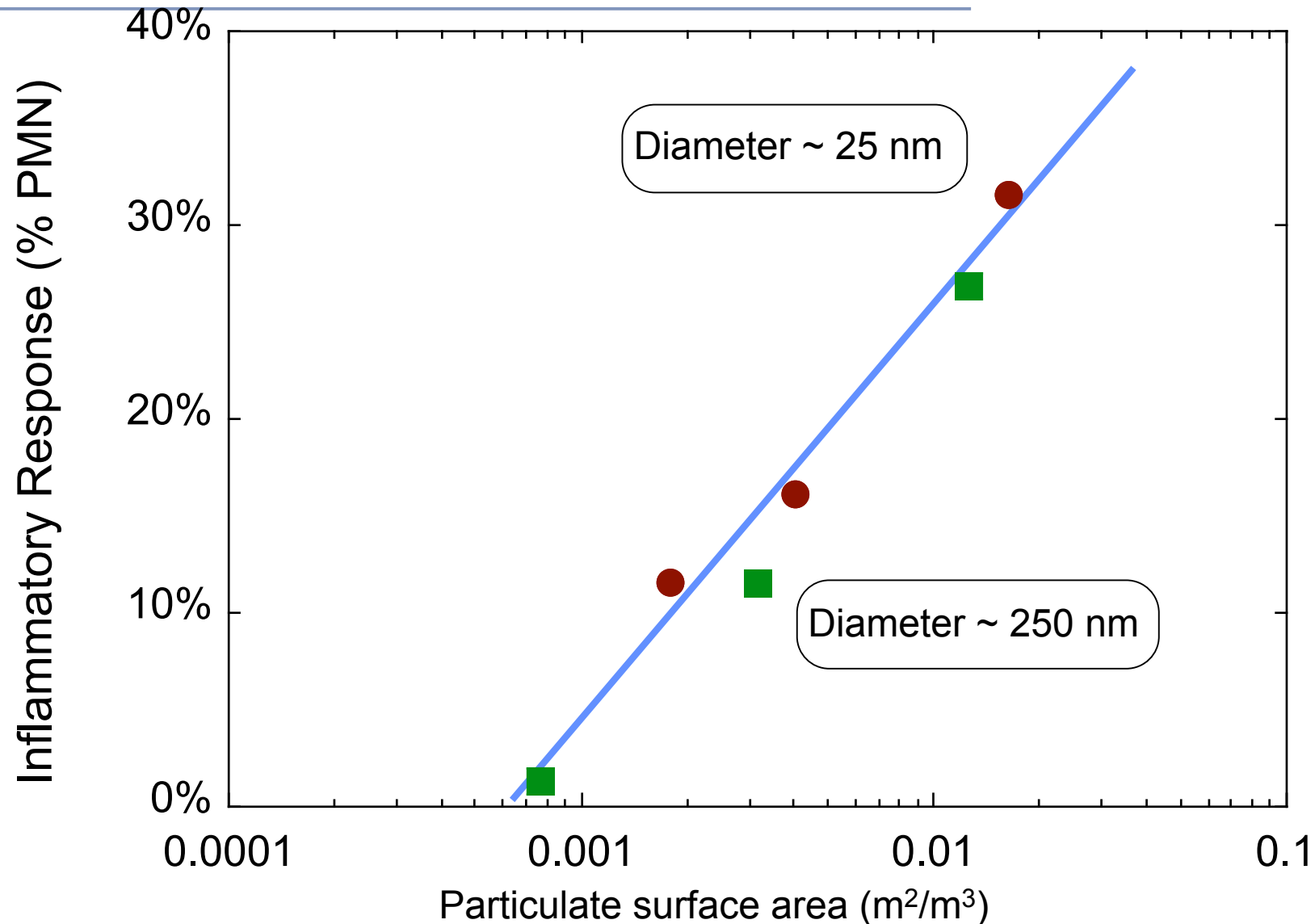


Oberdörster, G. (2000) *Phil. Trans. Roy. Soc. London Series A* **358**(1775): 2719-2740.



TiO₂ Instillation in Rats - Surface Area

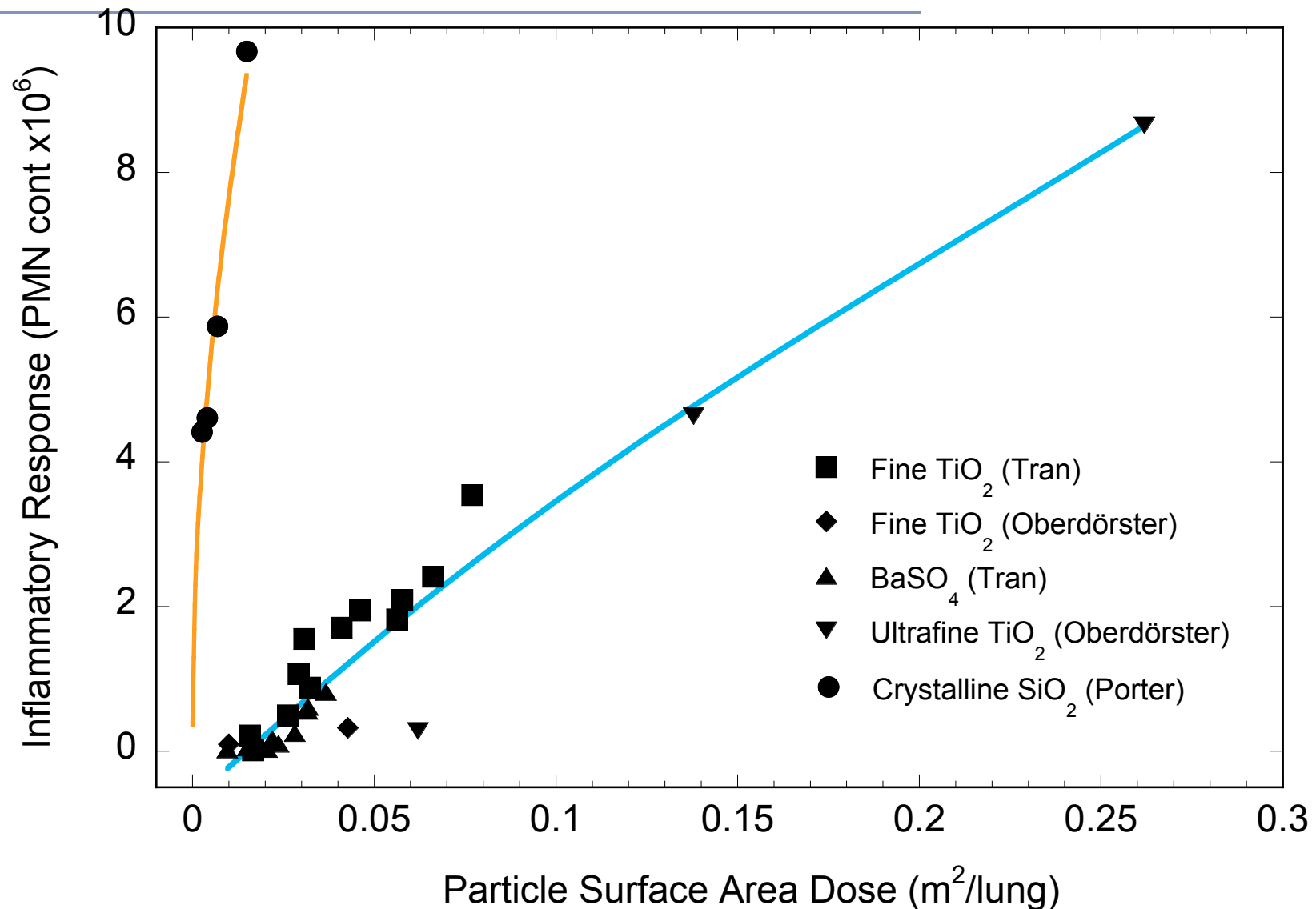
Oberdörster et al. (2000)



Oberdörster, G. (2000) *Phil. Trans. Roy. Soc. London Series A* **358**(1775): 2719-2740.

Significance of Surface Activity

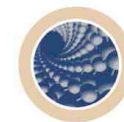
Comparison between low and high activity materials



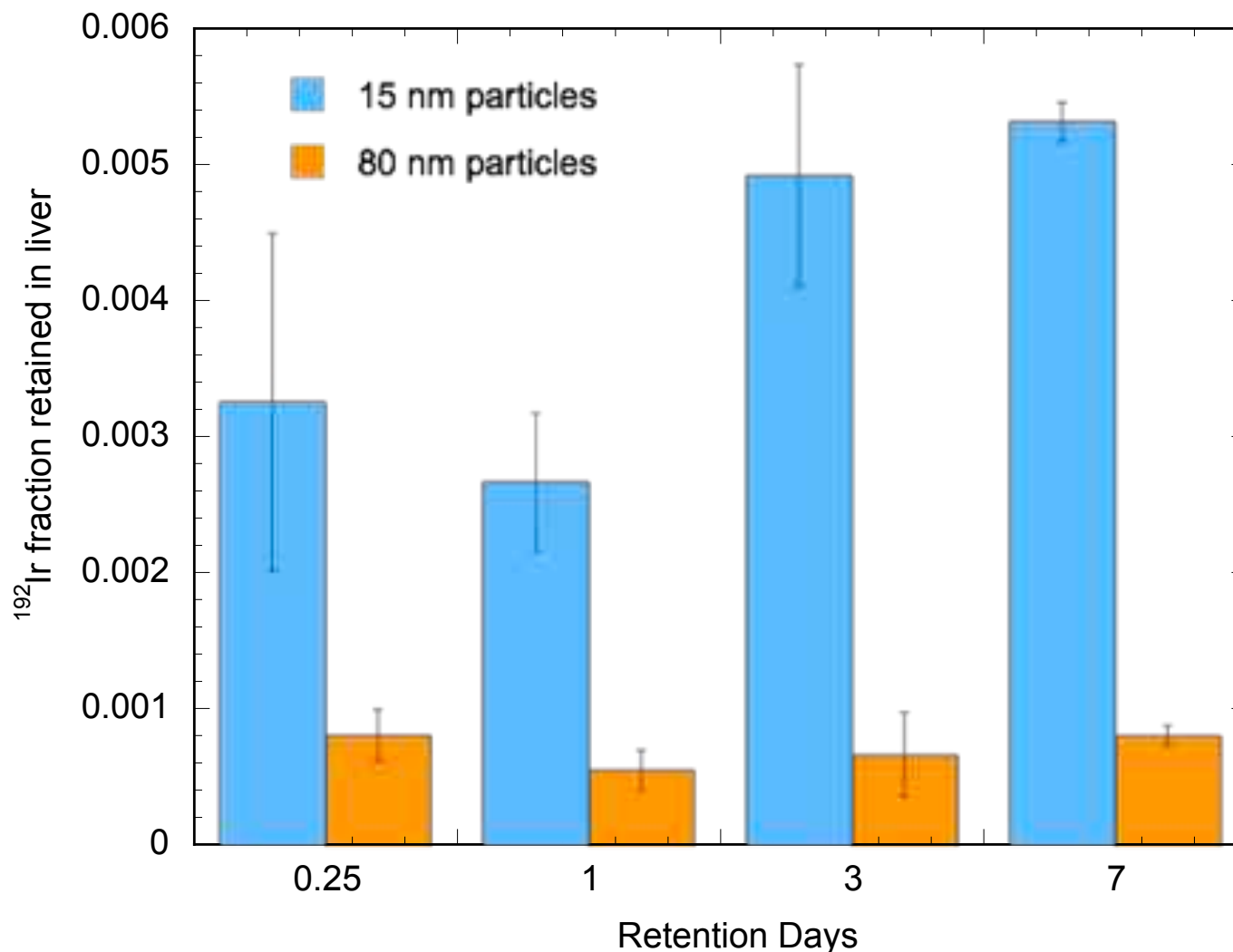
Maynard and Kuempel (2005), Journal of Nanoparticle Research, In Press

Particle Size

Translocation Following Inhalation - Lungs to Liver



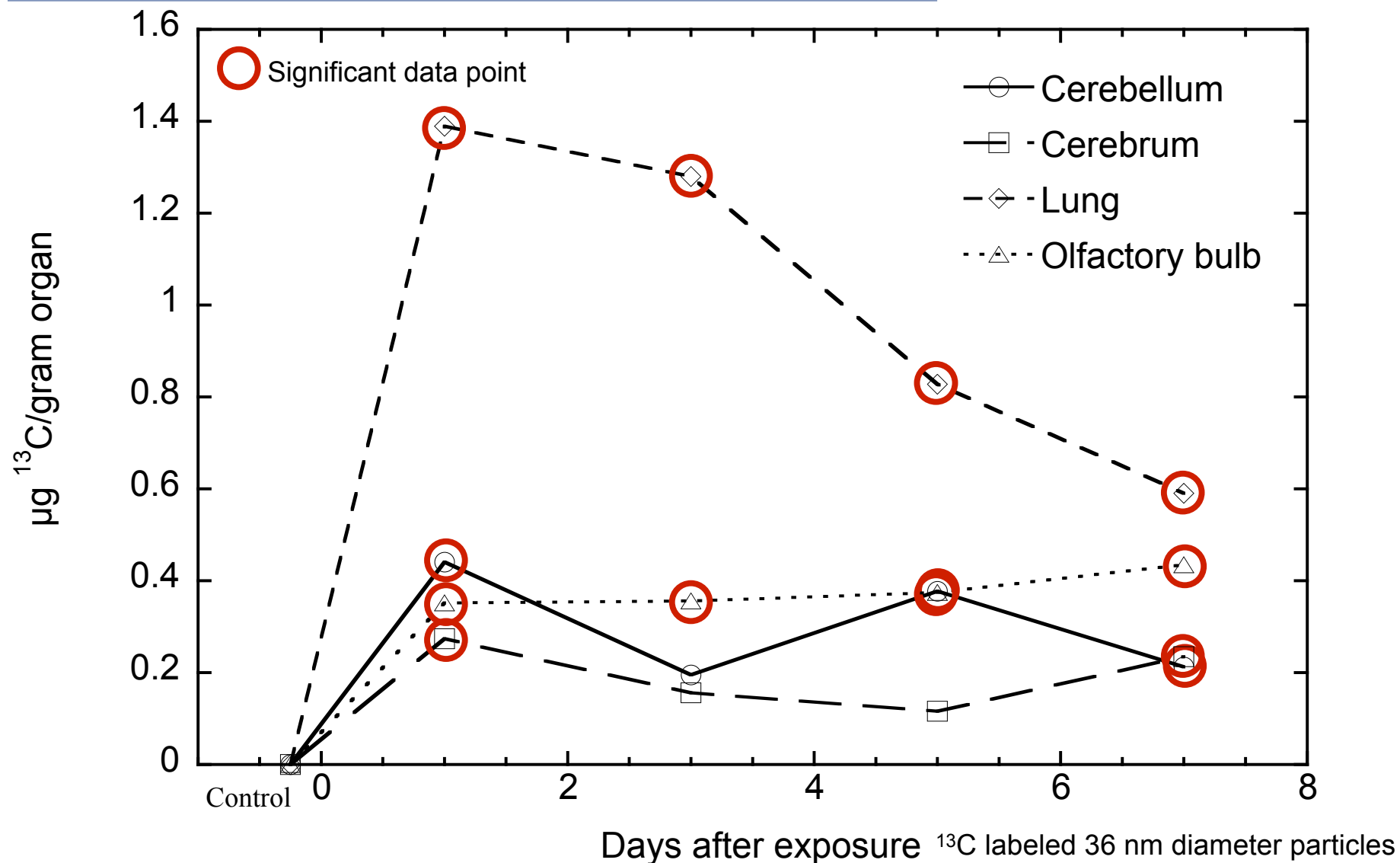
Fraction of inhaled insoluble ^{192}Ir translocating to liver in rats



Kreyling, W. G. et al. (2002). *J. Toxicol. Env. Health Pt A* **65**(20): 1513-1530.

Particle Size

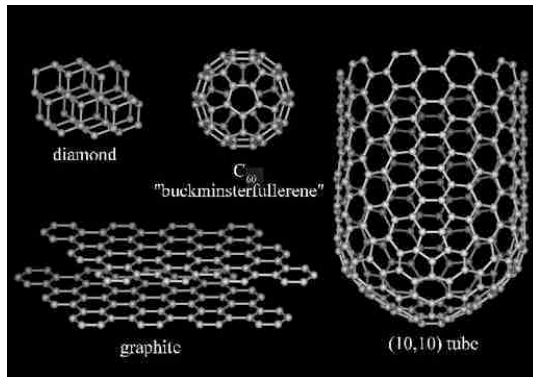
Translocation Following Inhalation - Upper airways to brain



Oberdörster, G., Z. Sharp, V. Atudorei, A. Elder, R. Gelein, W. Kreyling and C. Cox (2004). *Inhal. Toxicol.* **16**(6-7): 437-445.

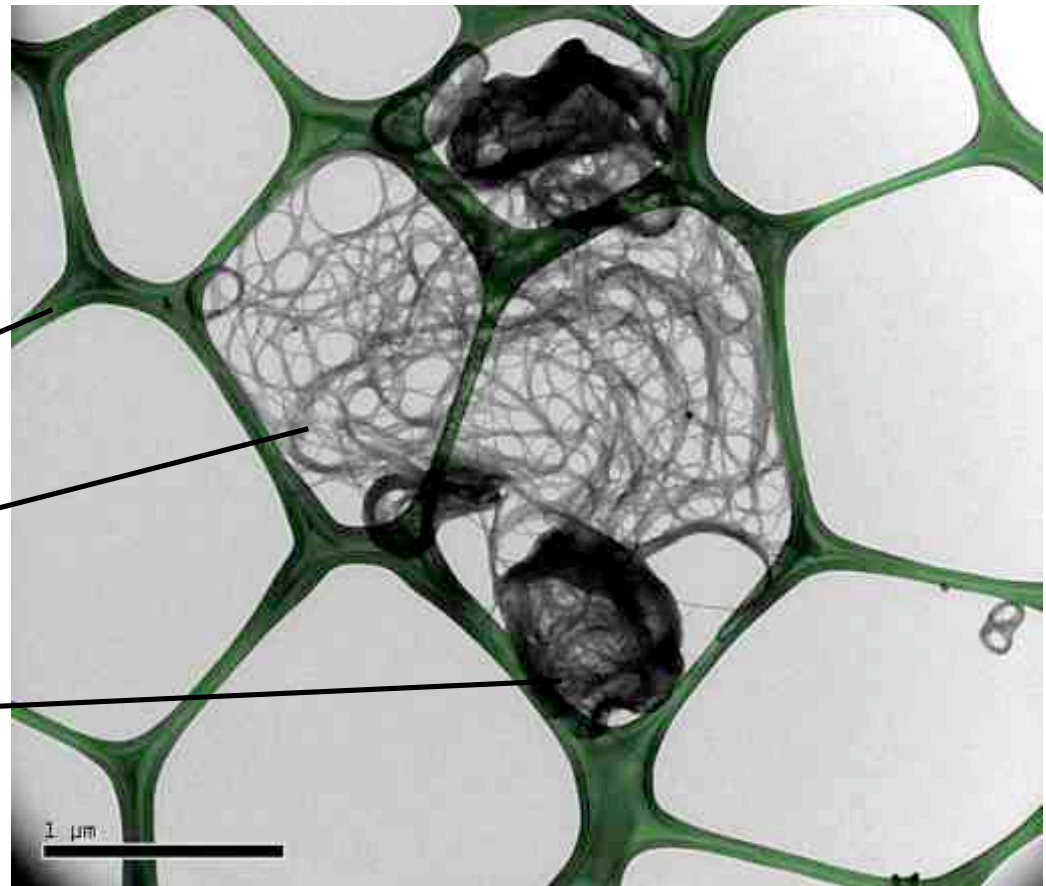
Significance of Morphology

Single Walled Carbon Nanotubes



Allotropes of carbon

Transmission Electron Microscope image of purified single walled carbon nanotube particles



Carbon support film

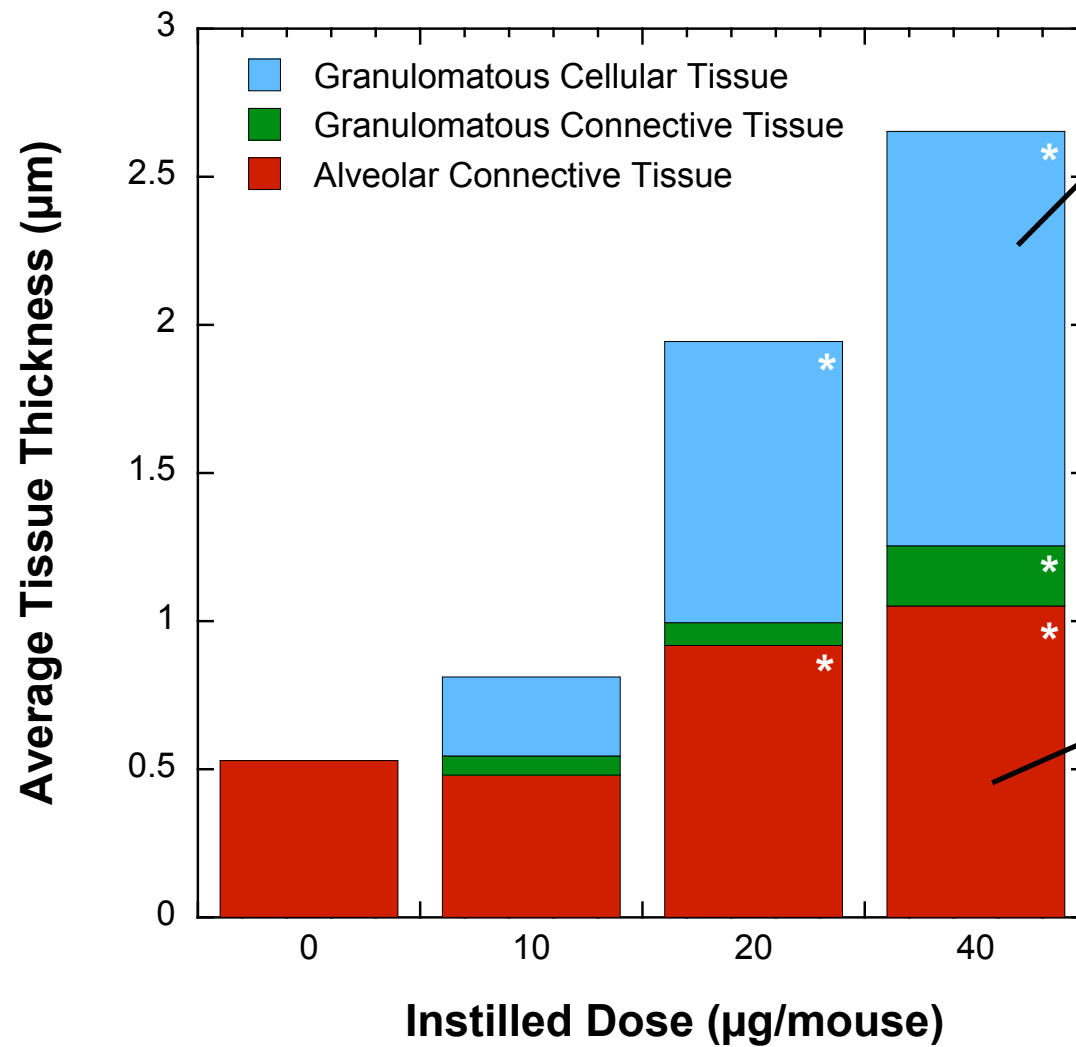
Open structured particles

Closed structured particles

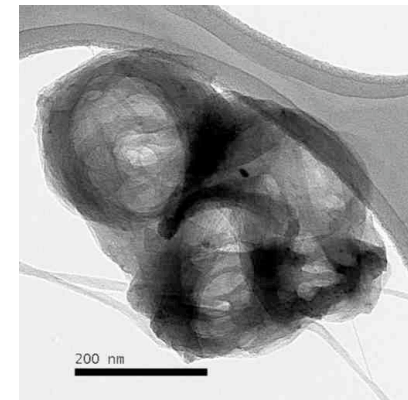
Ku, Evans, Ramsey and Maynard, in Shvedova et al. (2005)

Single Walled Carbon Nanotubes

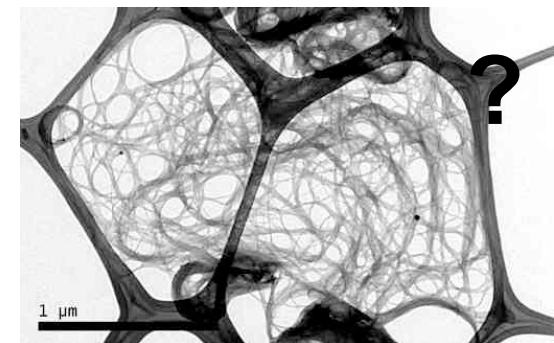
Tissue thickening in mice - Pharyngeal aspiration



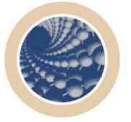
Proximal region of lung
Visible SWCNT clumps



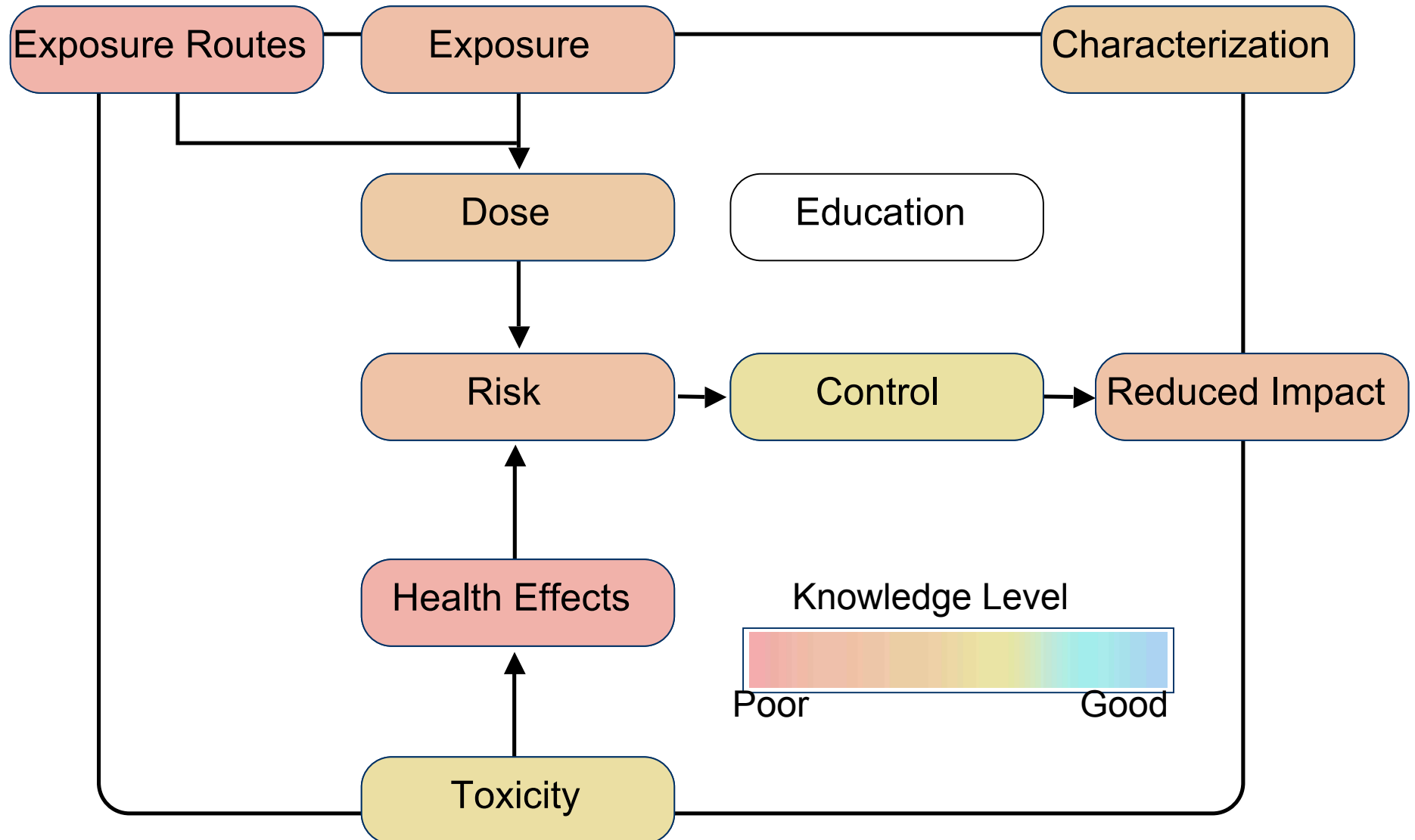
Distal region of lung
No SWCNT visible

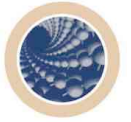


Shvedova, et al. (2005) *Am. J. Physiol.-Lung Cell. Mol. Physiol.* 289, 698-708.



Addressing Occupational Impact

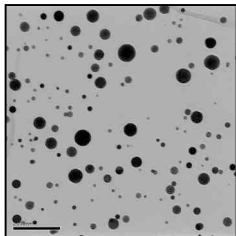




Setting Boundaries

Engineered nanomaterials which potentially present new challenges

- Criteria:
 - Nanomaterials capable of entering or interacting with the body
 - Nanomaterials which potentially exhibit nanostructure-dependent biological activity



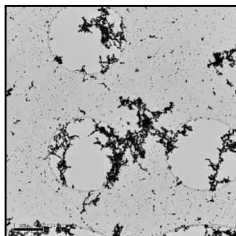
Nanoparticles

Simple, complex, “smart”.
Aerosols, powders,
suspensions, slurries



Comminution

Aerosols from grinding,
cutting, machining
nanomaterials



Agglomerates
or aggregates of
nanoparticles



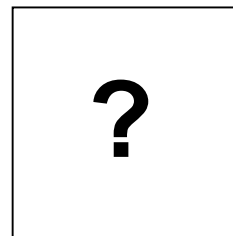
Degradation/Failure

Aerosols and suspensions
resulting from degradation
and failure of nanomaterials



Aerosolized suspensions

Including slurries and
solutions of nanomaterials



Unintentional use

Potential exposure from
unanticipated/unintentional
use



Monitoring Nanoscale Aerosol Exposures

Options

- Adapt current mass-based approaches
 - Continuity with the past
 - Sensitivity and relevance issues
- Measure size distribution
 - Provides a lot of information
 - Impractical in many instances
- Monitor number concentration
 - Relatively simple
 - Difficult to differentiate between process-related and background aerosols
 - Relevance?
- Monitor aerosol surface area concentration
 - Relevant for some materials. Is this achievable?

Aerosol Surface-Area Measurement

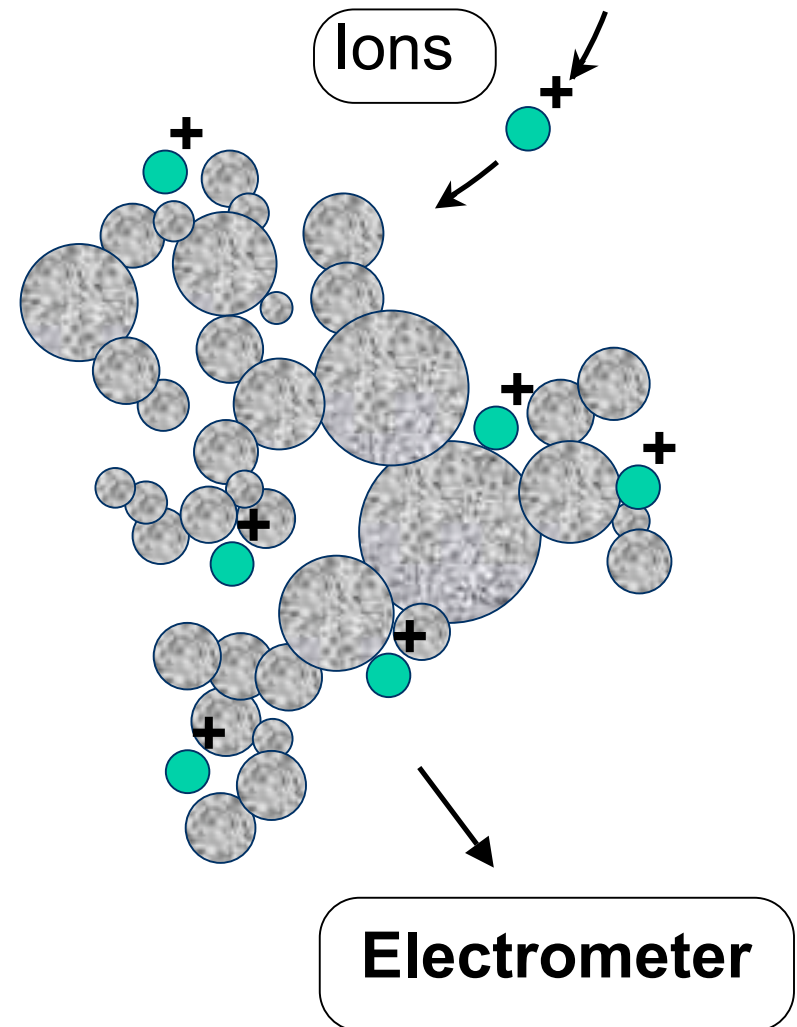
Using attachment rate



Charge on Aerosol \propto Surface Area

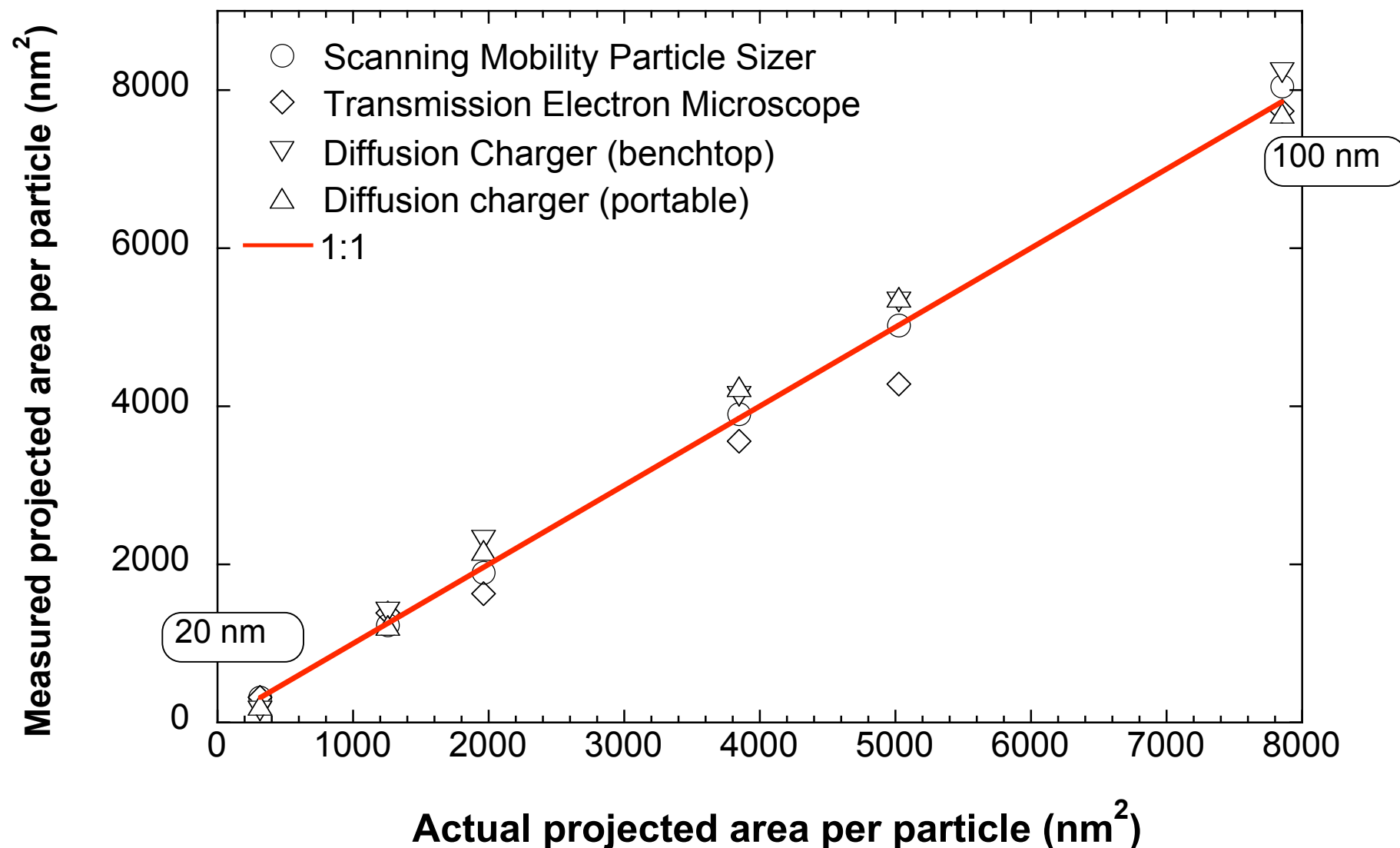
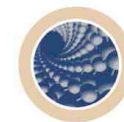


DC2000 CE Diffusion Charger
EcoChem



Comparison of Measurement Methods

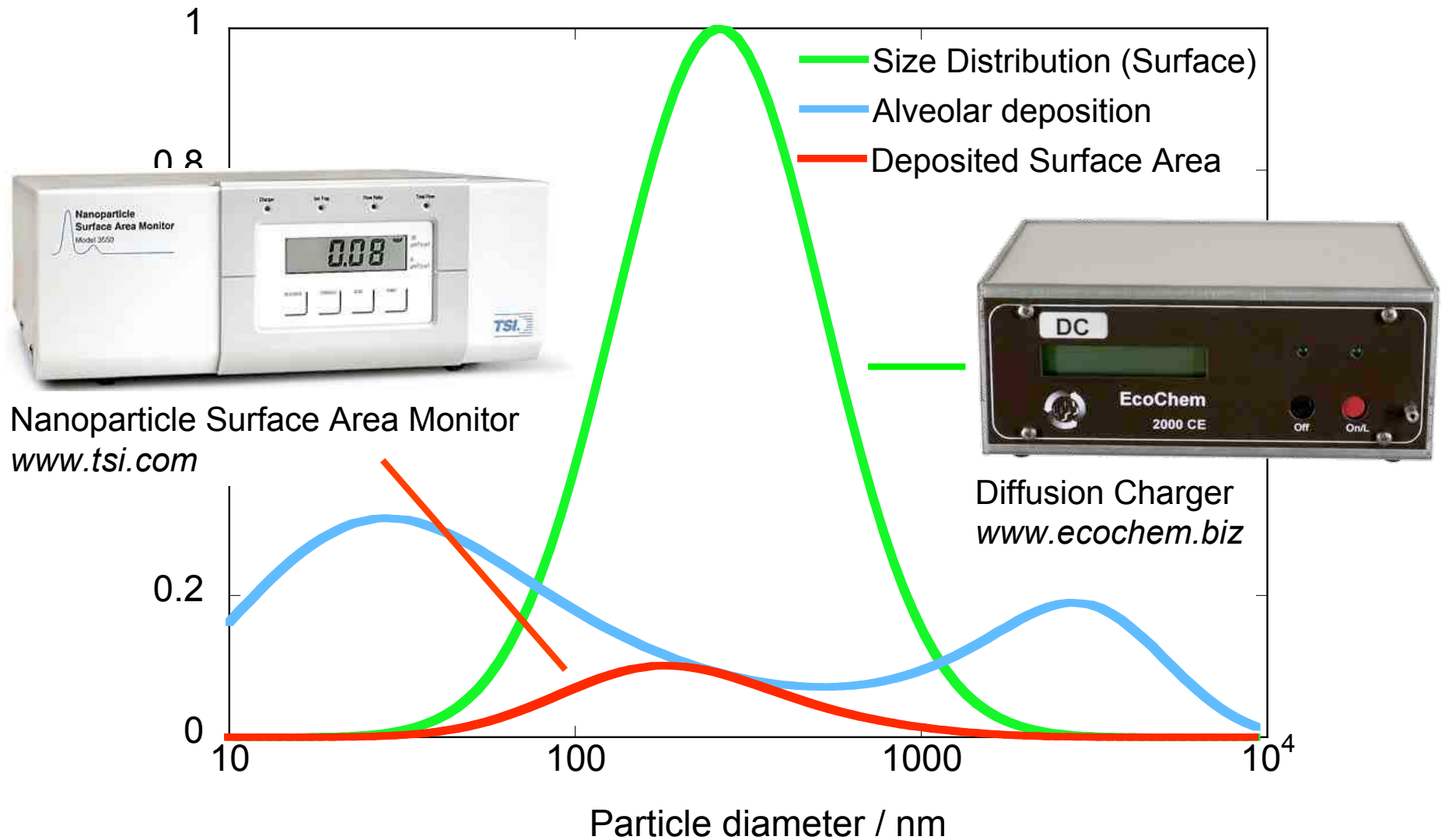
Monodisperse particles < 100 nm, fractal-like



Ku and Maynard, J. Aerosol Sci (in press)

Emerging Measurement Technologies

Deposited Surface Area



Wilson et al. (2004)

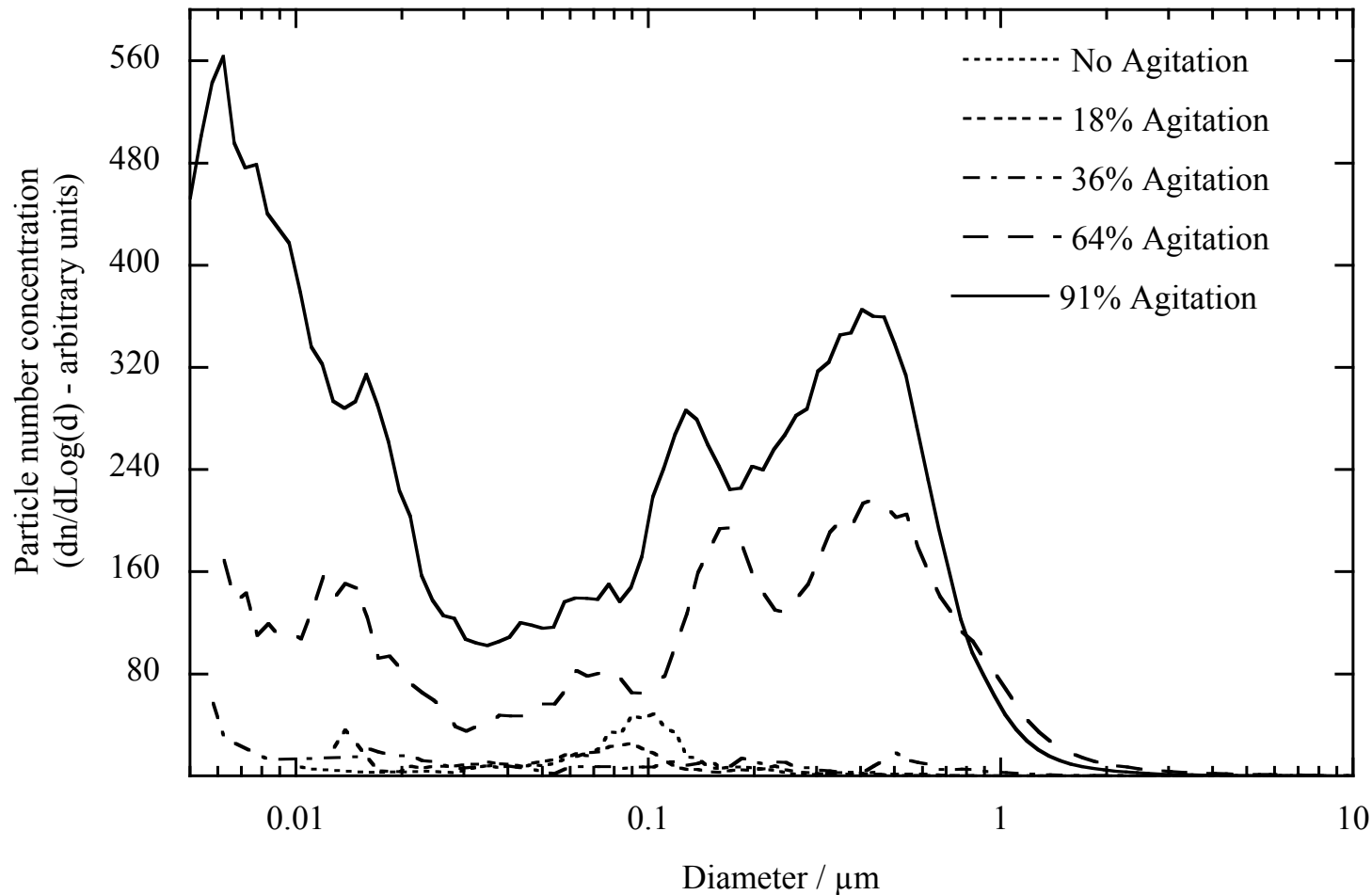
Handling Nanotube Material



Unprocessed single walled nanotube material



Laboratory Generation of Nanotube Aerosol

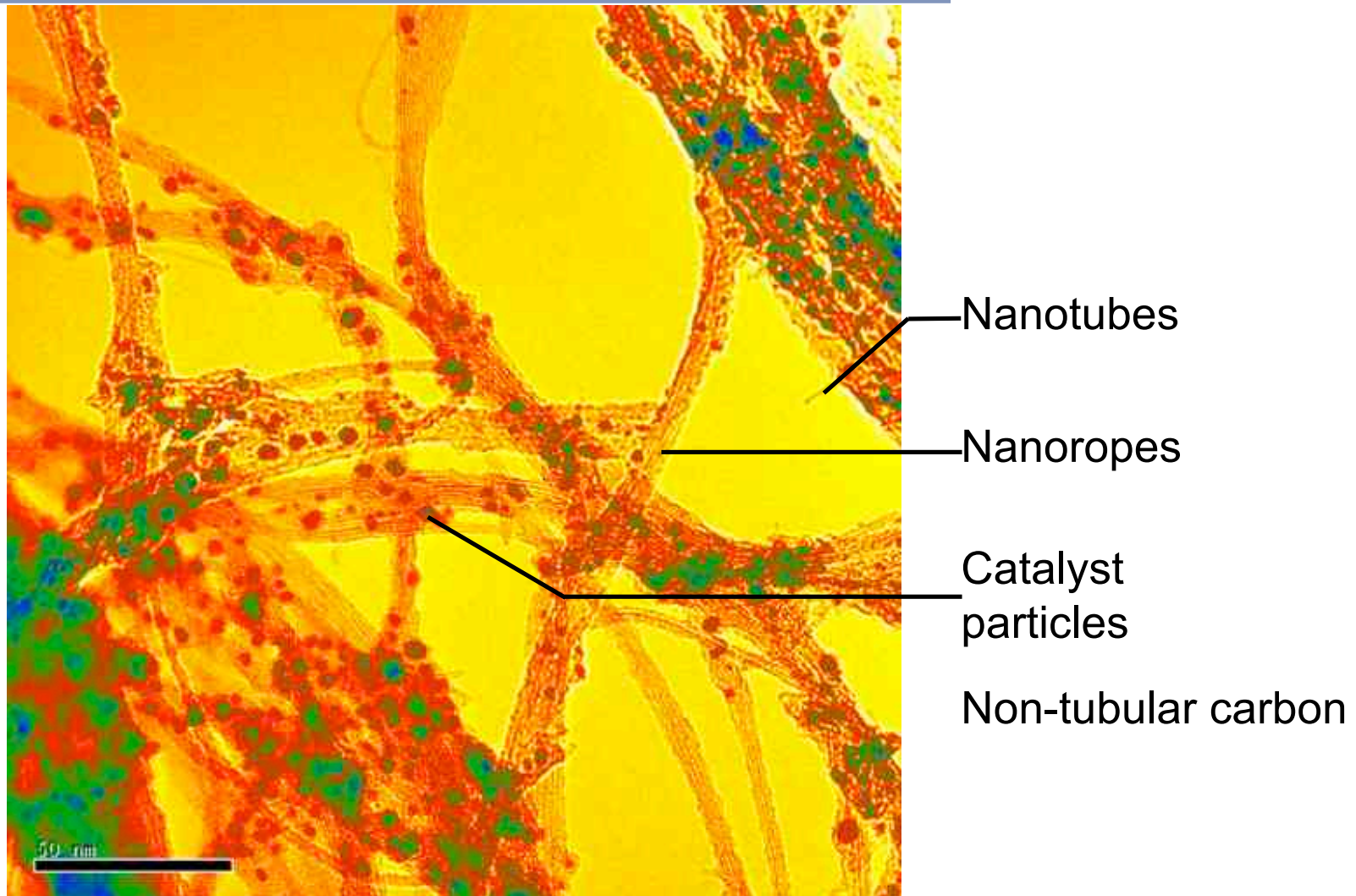


Agitation of unprocessed material in an airflow

Maynard, A. D., P. A. Baron, M. Foley, A. A. Shvedova, E. R. Kisin and V. Castranova (2004). *J. Toxicol. Environ. Health* **67**(1): 87-107.



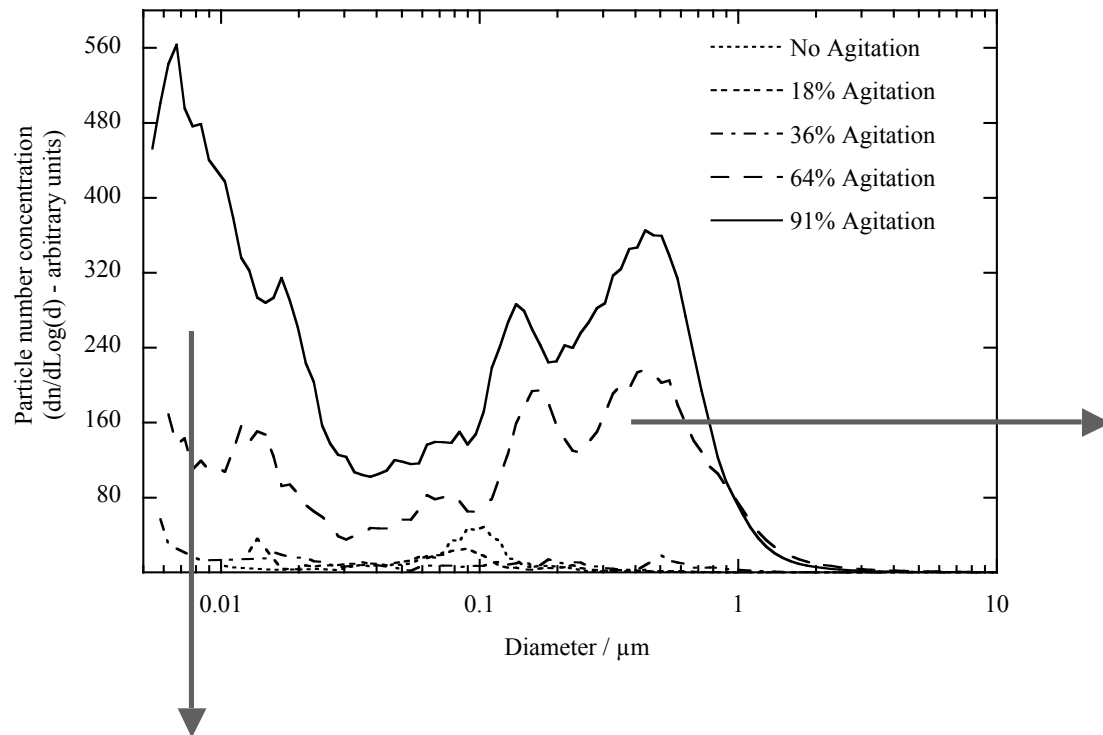
Single Walled Carbon Nanotubes



Raw single walled carbon nanotube material.

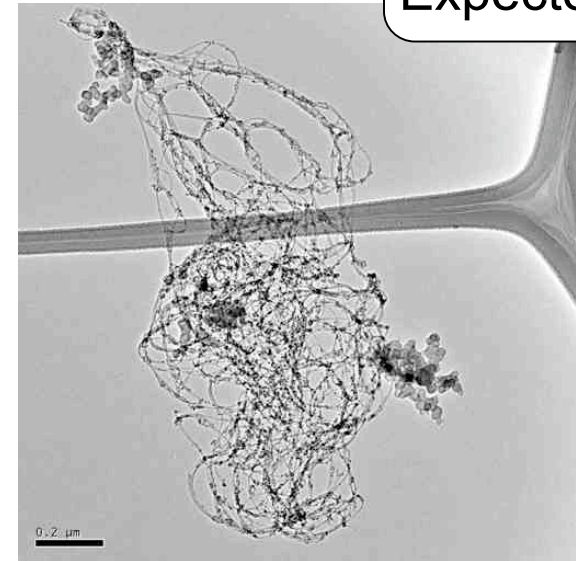


Nanotube Aerosol Characterization

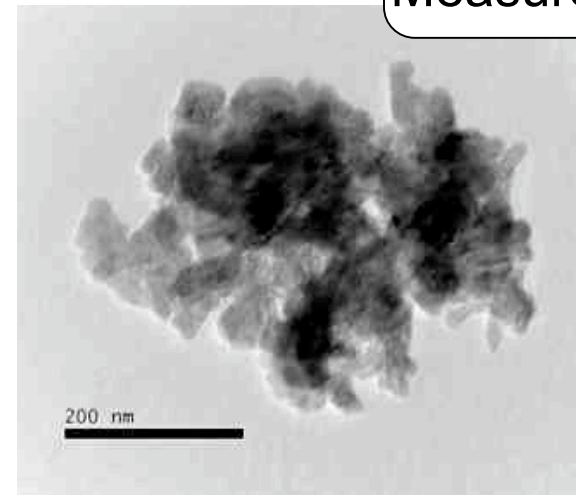


- **Physical/Chemical Characteristics?**
- Discrete carbon nanotubes or nanoropes?
- Transition metal catalyst particles?
- Non-tubular carbon?

Expected

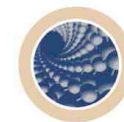


Measured

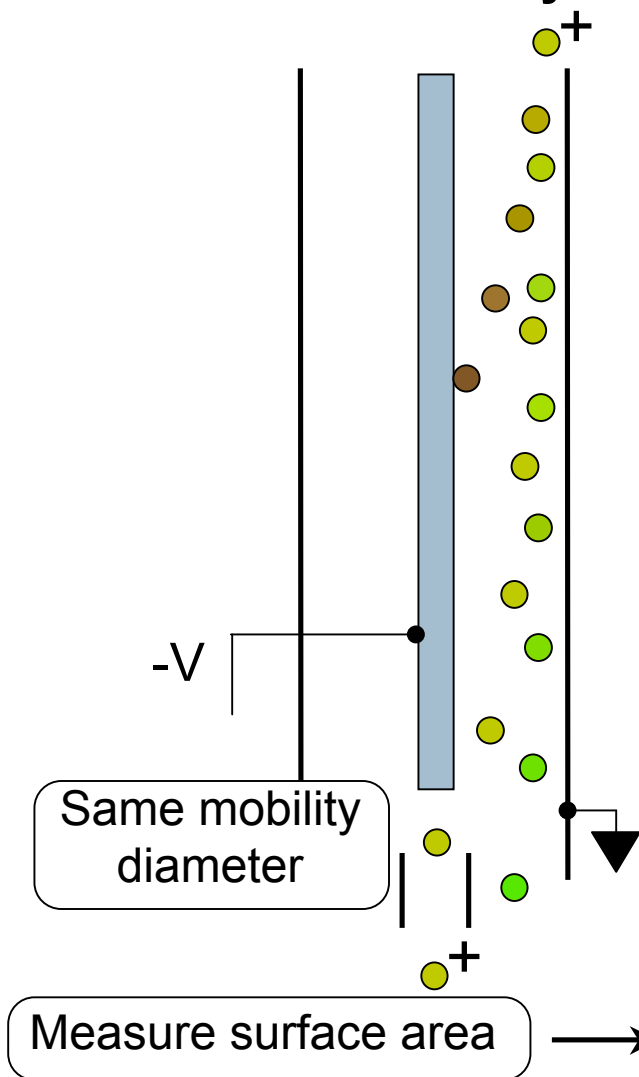


Aerosol Characterization

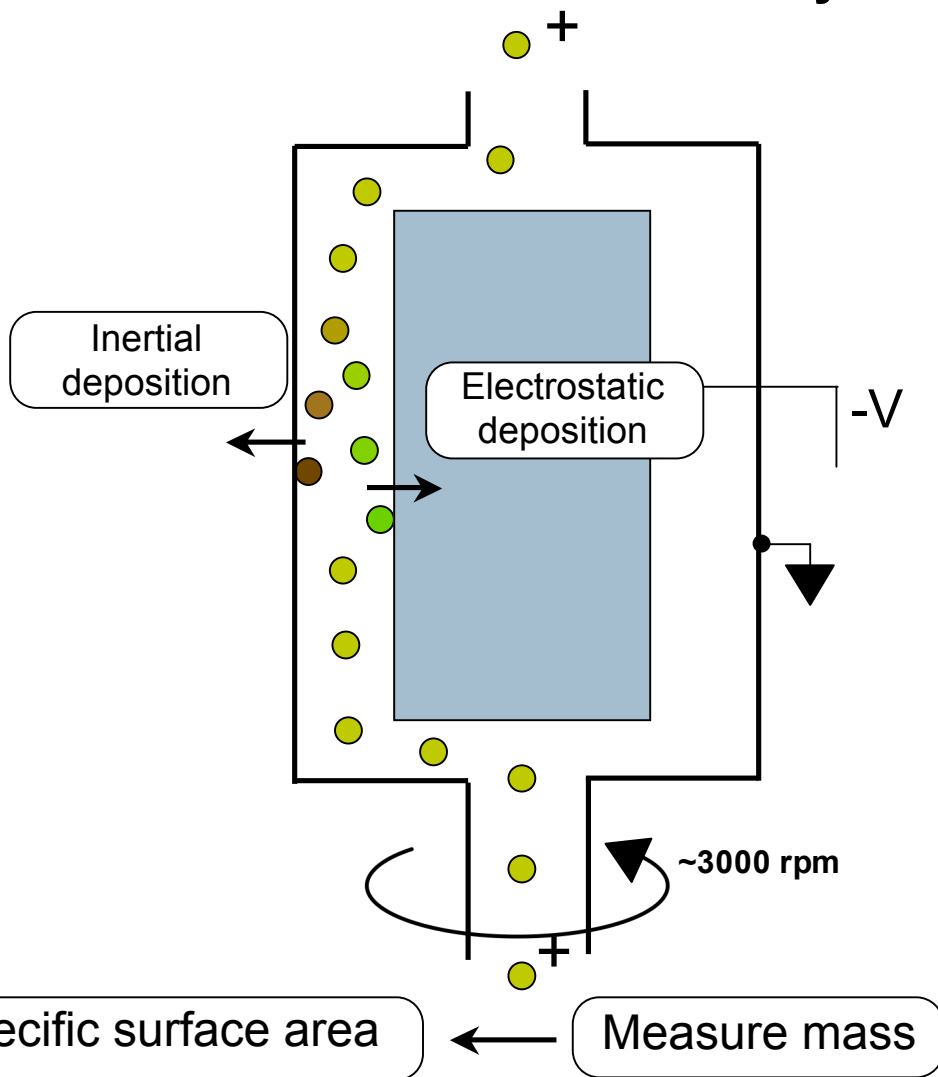
'Active specific surface area' measurements



Differential Mobility Analysis



Aerosol Particle Mass Analysis



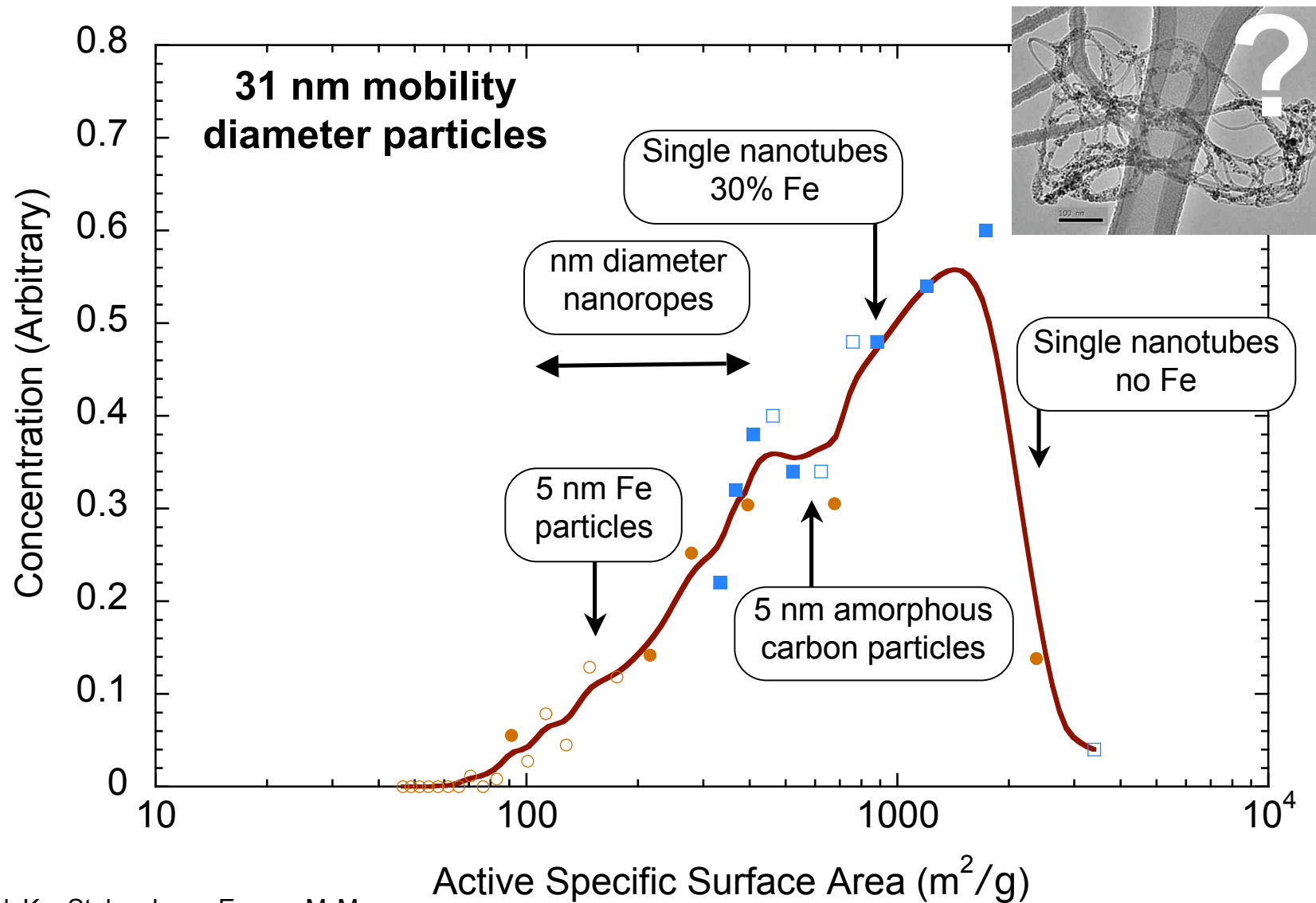
Measure surface area

Specific surface area

Measure mass

Aerosol Characterization

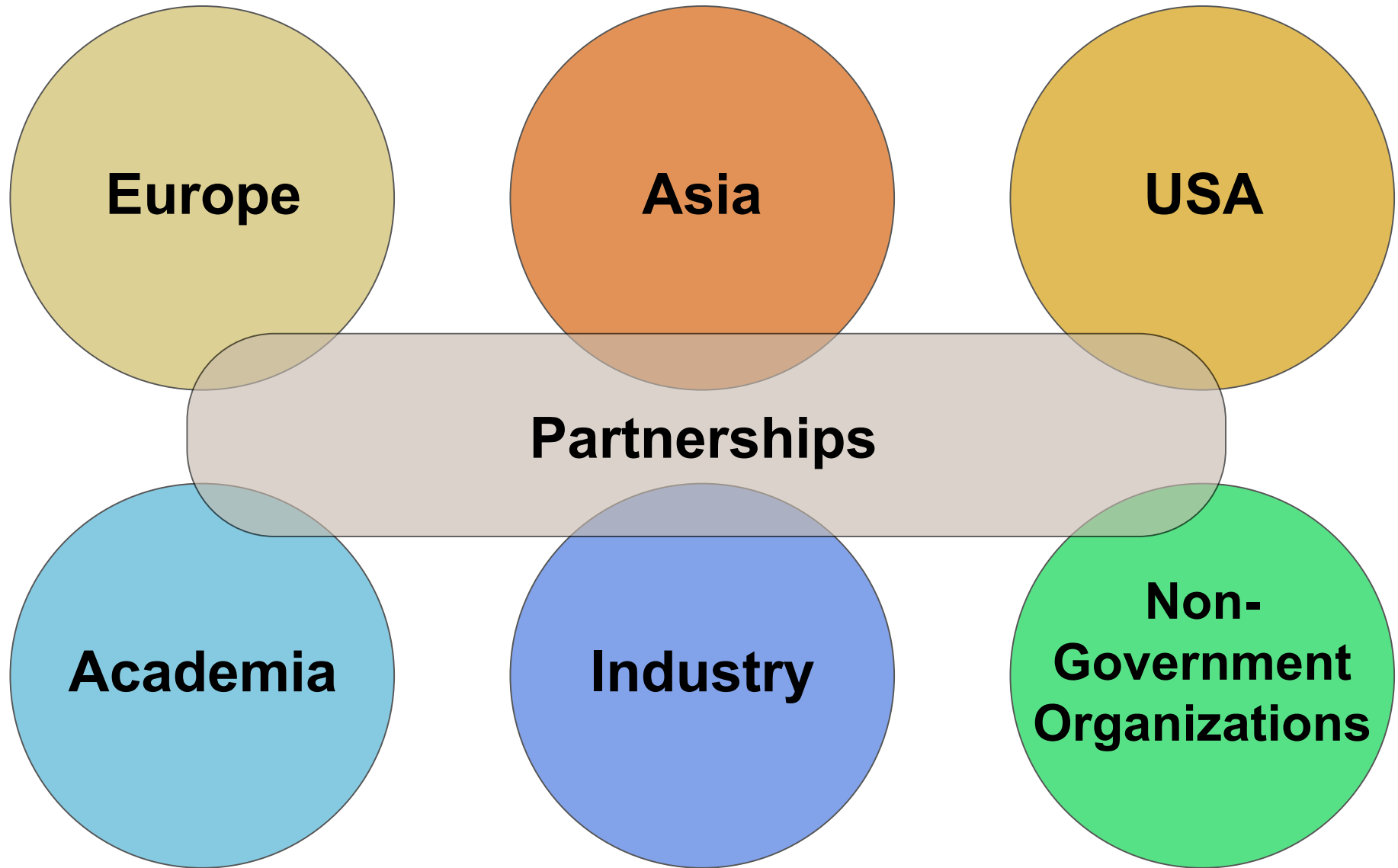
'Active' specific surface area



Maynard, Ku, Stolzenburg, Emery, McMurry

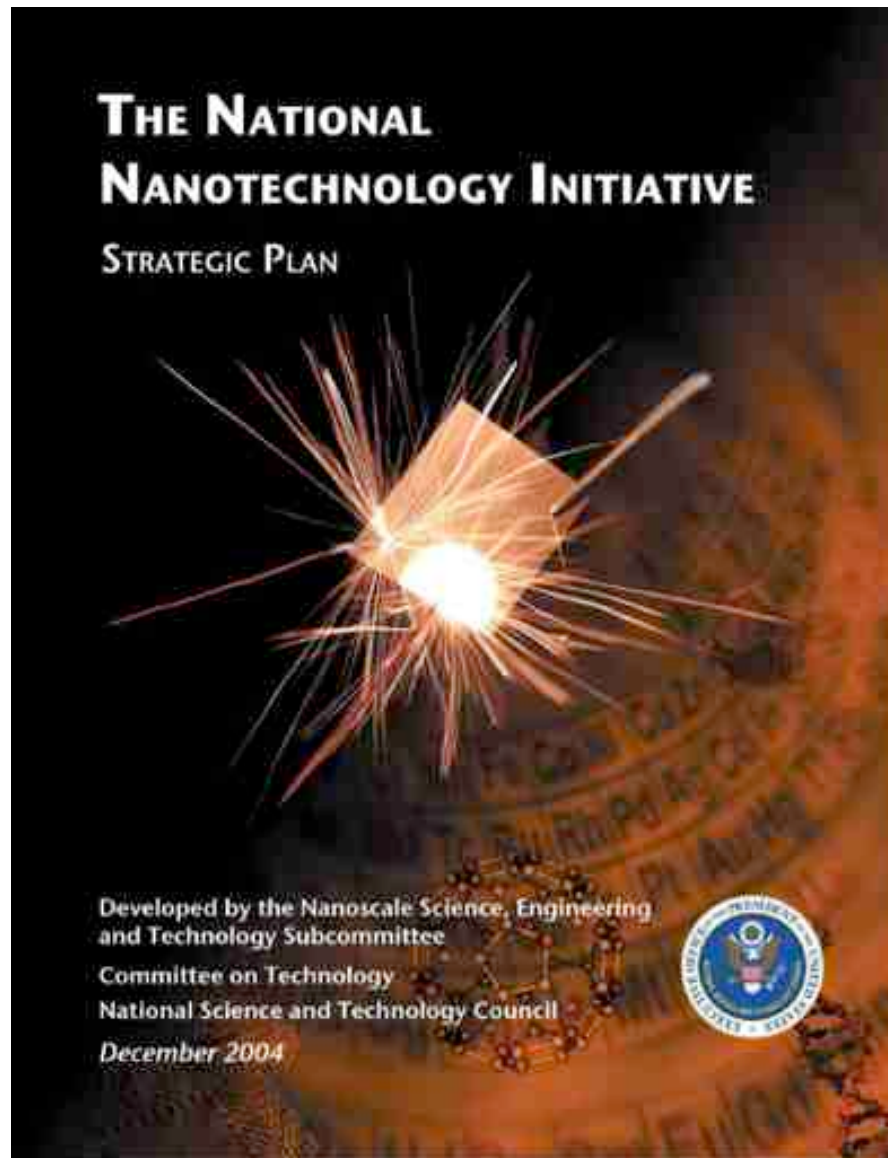
Impact of Engineered Nanomaterials

Global initiatives



National Nanotechnology Initiative

Strategic Plan



- **Goal 4: Support responsible development of nanotechnology:**

- Environmental, health and safety implications
- Ethical, legal and all other societal issues

- **Program Component Area 7: Societal Dimensions**



- Environmental, health and safety research
- Education
- Broad societal implications

www.nano.gov

Working with Engineered Nanomaterials

NIOSH





National Institute for Occupational Safety and Health

[CDC Home](#) | [CDC Search](#) | [CDC Health Topics A-Z](#)

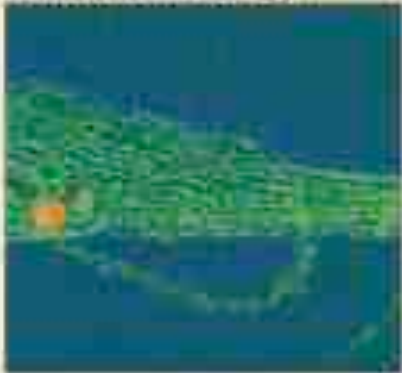
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NIOSH Safety and Health Topic:
Nanotechnology

**Strategic Plan for NIOSH Nanotechnology Research:
Filling the Knowledge Gaps**

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The National Institute for Occupational Safety and Health (NIOSH) is pleased to present the *Strategic Plan for NIOSH Nanotechnology Research: Filling the Knowledge Gaps*, September 2005. The strategic plan provides a guide for building a research effort capable of responding to the challenges of this emerging technology. It represents a timely research agenda and will evolve as new information becomes available and a more thorough scientific understanding about nanotechnology develops. The strategic plan describes a multi-dimensional research agenda. It addresses what NIOSH is doing internally and externally to lead the occupational safety and health community collaboratively in nanotechnology research. The strategic plan ([full text](#)) can be downloaded for a complete description of NIOSH's activities in the area of nanotechnology. [Printer Friendly Version](#) (PDF 432 kb, 111 pages) version of the full text.



Nanotechnology

[Nanotechnology Home](#)

[Approaches to Safe Nanotechnology: An Information Exchange with NIOSH](#)

www.cdc.gov/niosh/topics/nanotech/strat_plan.html

Working with Engineered Nanomaterials

NIOSH





NIOSH *National Institute for Occupational Safety and Health*

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NIOSH Safety and Health Topic:
Nanotechnology

**Approaches to Safe Nanotechnology:
An Information Exchange with NIOSH**

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Director's Message

The field of nanotechnology is advancing rapidly and will likely revolutionize the global industry. As with any new technology, we are faced with many unknowns; all of which raise questions concerning occupational safety and health. The National Institute for Occupational Safety and Health (NIOSH) is committed to ensuring worker protection as nanotechnology develops.

NIOSH has developed the document *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH* to raise awareness of potential safety and health concerns from exposure to nanomaterials. The document also addresses current and future research needs essential to understanding the potential risks that nanotechnology may have to workers.

It is imperative that the scientific community come together to advance our understanding of nanotechnology and its implications in the workplace. I invite you to participate in this process and encourage you to provide feedback, comments, or suggestions regarding the *Approaches to Safe Nanotechnology* document. I also encourage you to share any relevant information or experience pertaining to the field of nanotechnology.

As our knowledge grows, NIOSH plans to provide valuable guidance to the safe handling of nanoparticles and other safe approaches to nanotechnology. This will be an effort that evolves as the technology advances and our knowledge and experience grows.

Nanotechnology

Topic Index:
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[Approaches to Safe Nanotechnology: An Information Exchange with NIOSH](#)
[Strategic Plan for NIOSH Nanotechnology Research](#)
[Frequently Asked Questions](#)
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[Focus on Nanotechnology - Latest Developments at NIOSH](#)

www.cdc.gov/niosh/topics/nanotech/nano_exchange.html

Project on Emerging Nanotechnologies

Woodrow Wilson International Center for Scholars



- **Goal**

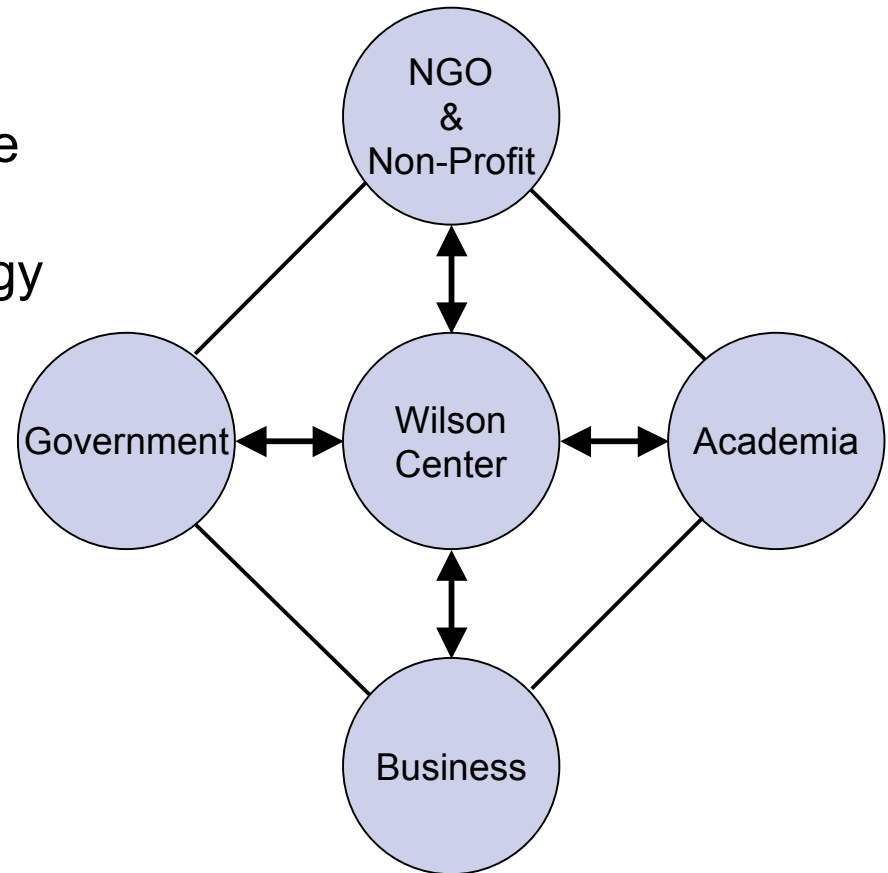
Ensure government and private sector address the risks as well as the benefits of nanotechnology

- **Budget**

\$3 million over 2 years

- **Programs**

Meetings, research, polling, outreach



Created July 2005 in partnership with the Pew Charitable Trusts

www.nanotechproject.com

Project on Emerging Nanotechnologies

Current activities include...



- Database of federally funded research on environmental, safety and health implications
 - Providing an overview of research focuses and gaps
- Review of airborne nanomaterial exposure measurement requirements
 - Evaluating current capabilities and research/development needs
- Use of gene arrays in ecotoxicity screening
 - Developing rapid, cost-effective screening assays for early detection of potential issues
- Facilitating domestic and international partnerships



Summary

- Nanotechnology is a revolutionary technology
- Significant societal and economic benefits are anticipated
- Conventional risk management models are being challenged
- Successful development and implementation of nanotechnology will require an integrated approach to risk
- Global, interdisciplinary and cross-sector partnerships are essential to developing sustainable nanotechnologies



Looking to the Future

Moving beyond the health impact of 'simple' nanomaterials

Photo by Maximilian Franz, courtesy of
Reactive nanotechnologies Inc.



Safety

"Unconventional" and unanticipated behavior

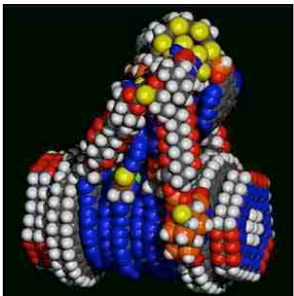
Kopeman & Philbert, UMICH



Complex nanoparticles and nano-devices

Moving beyond simple response mechanisms

♥ Institute for Molecular Manufacturing
www.imm.org



Convergence

Revolutionary Health & Safety Challenges

www.liftport.com



Contact Information

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www.nanotechproject.com